Mission Blue-Green

Elisa
Lähde

MISSION BLUE –GREEN

The Significance of Co-Creation to Promote Multifunctional Green Infrastructure within Sustainable Landscape and Urban Planning and Design in Finland

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List of Abbreviations and Symbols

ES	Ecosystem Service
GI	Green Infrastructure
LID	Low-Impact Development
SUDS	Sustainable Urban Drainage Systems
WSUD	Water-Sensitive Urban Design

LIST OF PUBLICATIONS

This doctoral dissertation consists of a summary and the following publications that are referred to in the text by their numerals.

1. Lähde, Elisa; Di Marino, Mina. 2018. Multidisciplinary collaboration and understanding of green infrastructure: Results from the cities of Tampere, Vantaa and Jyväskylä (Finland). *Urban Forestry and Urban Greening*. Volume 40, April 2019, pp. 63-72.
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3. Tapaninaho, R.; Lähde, E. 2019. Multi-stakeholder cooperation for green infrastructure: Creating sustainable value. In Day, A.K. and Lehtimäki, Hanna. (Eds.) *Evolving Business Models in Ecosystem of Disruptive Technologies and Social Media*. New Delhi: Bloomsbury, pp. 169–181.
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Publication 1. 'Multidisciplinary Collaboration and Understanding of Green Infrastructure: Results from the Cities of Tampere, Vantaa and Jyväskylä (Finland)'———The author was the main contributor to this publication. She led the collaborative efforts regarding the study design, data analysis, and results discussion. Mina di Marino participated in analysing and writing the paper and discussing the results.

Publication 2. 'Barriers Preventing Development of Integrated Stormwater Management in Helsinki, Finland'———The author was the main contributor to this publication. Kajsa Rosqvist participated in the practical implementation including collecting data and analysing and writing the paper.

Publication 3. 'Multi-Stakeholder Cooperation for Green Infrastructure: Creating Sustainable Value'———The author collaborated on the research design and practical implementation including collecting data and analysing and writing the paper. The author provided insight into co-framing the semi-structured interviews. Riikka Tapaninaho participated in the research design and practical implementation, including collecting and analysing data, writing the paper, and discussing the results.

Publication 4. 'Can We Really Have It All? Designing Multifunctionality with Sustainable Urban Drainage System Elements'———The author was the main contributor to this publication. She led the collaborative efforts regarding the study design, data analysis and results discussion. Ambika Khadka was responsible for designing, preparing and analysing quantity and quality results related to water. She also participated in writing the article. Teemu Kokkonen also participated in writing the article. Outi Tahvonen participated in designing and analysing the amenity- and biodiversity-related results and writing the article.

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ABSTRACT

We are undeniably living in an era of enormous environmental crisis, with climate change and species extinction as its most outstanding features. These issues challenge our societal systems and relationship with nature. In addition, more than half of the planet's population lives in urban areas, where environmental problems tend to culminate and where counter-active efforts should be concentrated.

Green infrastructure (GI) is a prominent approach to solving urban environmental issues. Generally, GI can be defined as an interconnected green space network that is planned and managed for its natural resources and values and for the associated benefits to the population. Within urban settings, GI can be defined as a strategic network of planned and unplanned urban green and blue spaces that help cities meet several urban challenges by delivering ecosystem services. This emerging concept has been considered a promising framework to connect natural and semi-natural systems using spatial planning policies and practices and, thus, to promote sustainability and climate resilience.

Solving complex sustainability-related problems requires inputs from various communities of knowledge. In this doctoral dissertation, the aim is to study the possibilities and potentials of co-creation to promote GI in different phases of urban and landscape planning and design. The methodological approach is action research, which has been implemented in four case studies in five Finnish cities. In all the cases, the adaptation of a scientific co-creation model has been the main approach to both 1) participating in the development process for a case site and 2) collecting data for the research.

The study of co-creation-led urban development processes, including the identification of existing barriers, reveals some of the critical factors and gaps in effectively adopting the GI approach in urban planning and design. The result of the study is an accelerating model that can be used as a concrete tool to boost co-creation in the planning and design of multifunctional green infrastructures. The GI-based approach challenges planning traditions and the conventional methods we have used to envision and construct our cities. Implementing the GI-based approach and supporting the planning and design of GI elements through co-creation helps us to reorganise our actions and processes related to biophysical structures and natural processes in urban areas and to better provide desired ecosystem services. Thus, co-creation can support the use of the GI-based approach as a game-changer that facilitates regime shift to adaptive governance, enabling systemic change from existing practices to a wider socio-ecological systems approach. The co-creative processes of planning and design of GI can be used as a platform to increase both the multifunctionality of GI solutions and the joint understanding of urban socio-ecological systems as a basis for sustainability.

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Helsinki, August 2020
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INTRODUCTION

Currently, we are living in an era of substantial environmental crisis, with the most outstanding features being climate change and species extinction. These issues challenge our societal systems and relationship with nature. Another megatrend is urbanisation, as more than half of the planet's population lives in urban areas, where environmental problems tend to concentrate. As an example, climate change can locally increase both the heat island effect and precipitation, leading to increased health and flood risks, especially in dense urban settings (Gill et al., 2007). Furthermore, new land-use development typically negatively affects natural environments, the related habitats, and local biodiversity, making urbanisation one of the most notable drivers of species extinction (Newbold et al., 2015).

Green infrastructure (GI) is a prominent approach to solving urban environmental issues and can be defined as 'an interconnected green space network (including natural areas and features, public and private conservation lands and other protected open spaces), that is planned and managed for its natural resources and values and for the associated benefits to the population' (Benedict and McMahon, 2012, p. 3). Within urban settings, GI is defined as a strategic network of planned and unplanned urban green and blue spaces that help address several urban challenges by delivering ecosystem services (ESs; Norton et al., 2015). Furthermore, the GI-based approach has been applied frequently to solve urban water issues (Flynn and Davidson, 2016). In some cases, the term *GI* has been used to address urban drainage solutions (Fletcher, 2015) or has been denoted as blue-green infrastructure. Despite its vagueness and multiple definitions, the emerging concept has been considered a promising framework to integrate natural processes within spatial planning policies and practices and, thus, to promote sustainability and climate resilience (Ahern, 2007; Lennon and Scott, 2014).

Solving complex sustainability-related problems requires input from various communities of knowledge (Mauser et al., 2013; Wyborn et al., 2019). More specifically, GI-related research often notes the collaboration between different stakeholders as one of the key factors for advancing GI-based approaches (i.e. Lennon et al., 2016; Faehnle et al., 2014; Ahern et al., 2014; Kopperoinen et al., 2014; Lafortezza et al., 2013; Mell, 2010). Interdisciplinarity and collaboration with stakeholders can enhance social, economic, and environmental benefits associated with the GI-based approach to urban planning and design by enabling a broader group of stakeholders to shape how the landscape is developed and managed. However, the potential composition of the stakeholder group, the scope of collaboration, and the urban development phases best suited to collaboration are not yet well established (Mell, 2017).

In this doctoral dissertation, the aim is to study the possibilities of collaboration to promote GI in different phases of landscape and urban planning and design processes through action research based on case studies. Following the growing body of literature promoting urban GI as a platform for knowledge, co-*creation* (Pauleit, 2019; Haase, 2017) was chosen as the specific manner of collaboration and was adapted to four Finnish case studies. Three of the four case studies included a strong emphasis on stormwater management, thus deepening the focus of the dissertation on sustainable urban drainage systems (SUDS).

This study of co-creation-led urban development processes, which includes the identification of existing barriers, enables the discussion of further conditions required for the effective adaptation of the GI-based approach in the context of landscape and urban planning and design and for realizing its subsequent benefits. The dissertation concerns the field of landscape architecture.

1.1 Aims and Research Questions

The overarching aim of this research is to understand how to co-create GI within landscape and urban planning and design in Finland and to determine what kind of further implementation is needed to strengthen the contribution of GI. The research is practice-oriented, as the overarching aim has been approached using four case studies dealing with the implementation of GI in different stages of urban development and the related working processes, knowledge needs, discussed barriers, and evaluation criteria. Within all the cases, the adaptation of a scientific co-creation model (Mauser et al., 2013) was the main approach to both participating in the planning or design process of a case site and collecting data for research purposes. The dissertation has two additional aims that are more concrete, that are related to each other, and that contribute to the overarching aim (Fig. 1).

The first part of the research concentrates on collaboration at the urban planning level. In this research, urban planning is understood as coordination of political and practical processes concerned with both strategic and statutory planning of land use in the urban context to create new qualities or assets (Van Assche et al., 2012). Accordingly, landscape planning is the component of urban planning processes concerned with physical, biological, cultural, and historical values and with the relationships and coordination between these values, other land uses, and the environment.

On the planning level, general outlines of the urban structure are formed, and GI and the hydrological cycle are combined with the technical and social structures of a city. Therefore, mistakes created in the planning phase are difficult to fix later in the GI solution design phase; thus, planning requires having a broad view. Accordingly, an additional aim of this work is to test the potential of co-creative processes to foster the adoption of a GI-based approach at the strategic planning level of urban development, with the goal of *understanding how co-creation can promote the development of more multifunctional GI*. The results allow further discussion, which is a required precondition for the effective use of the GI concept. This first portion of the research was conducted through two case studies, which are presented in the research papers ‘Multidisciplinary Collaboration and Understanding of Green Infrastructure: Results from the Cities of Tampere, Vantaa and Jyväskylä (Finland)' (Paper 1) and 'Barriers Preventing Development of Integrated Stormwater Management in Helsinki, Finland' (Paper 2). Both papers have specific research questions linked to the overall research aims in Fig. 1.

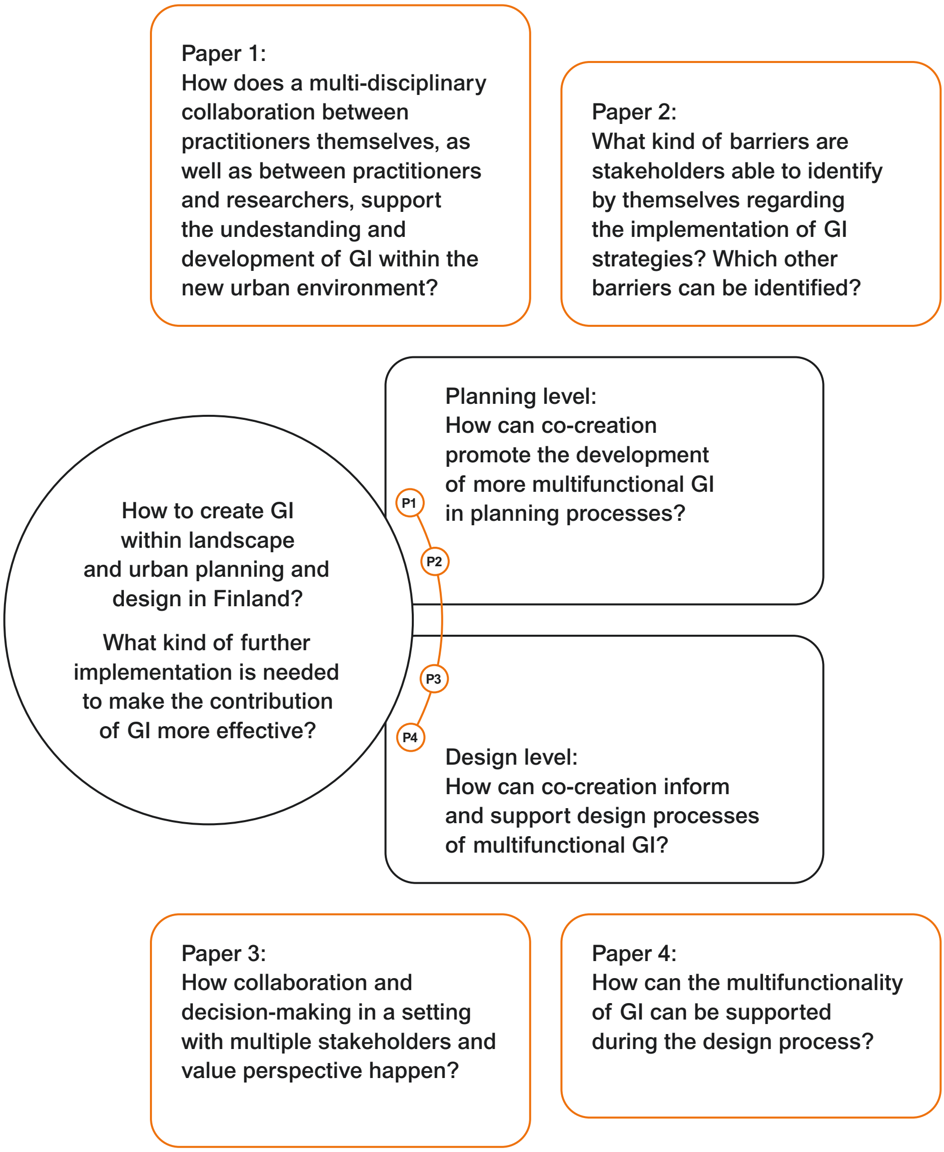

Fig 1. The main research question of the dissertation divided into two constituent aims, one concerning the planning level and the other concerning the design level; each includes two case studies. GI: green infrastructure. The additional aim and specific research questions of the papers related to the first part of the study on urban planning (papers 1 and 2), as well as to the second part of the study on urban design (papers 3 and 4).

In the second part of the research, the focus is on the GI solution design level. Design is understood as the process of designing and shaping the physical features of urban or landscape elements. It is creation and evaluation of the possible forms of something, including production (Van Assche et al., 2012).

The design of a GI solution is complex because the primary advantage of GI is multifunctionality (Hansen and Pauleit, 2014; Hansen et al., 2015). Multifunctionality is the capacity of a single solution to deliver multiple services. In the GI solution design process, water and vegetation are integrated with technical structures to deliver multifunctional benefits. The second part of this research addresses the design of GI solutions by defining the knowledge needs, design targets, and valuation criteria of GI solutions by asking *how can co-creation inform and support design processes of multifunctional GI?* This question is answered by conducting two more Finnish case studies (in the *Vauhtitie wetland* in Helsinki and the *Kirstinpuisto area* in Turku), whose outcomes were published in the research papers 'Multi-stakeholder Cooperation for Green Infrastructure: Creating Sustainable Value' (Paper 3) and 'Can We Really Have It All? Designing Multifunctionality with Sustainable Urban Drainage System Elements' (Paper 4), respectively. Both papers have specific research questions linked to the overall research aims displayed in Fig. 1.

1.2 Research Process and Dissertation Structure

This dissertation consists of three peer-reviewed journal papers and one peer-reviewed conference paper, which form the basis for the study. The list of publications with full bibliographical information is presented at the beginning of this dissertation.

The research was begun in 2014 by applying for funding and framing the overarching research questions, and it continued over five years until the beginning of 2020, as illustrated in Fig. 2. From the very beginning, GI and related stormwater solutions were the focus of the research, but during the process, the role of co-creation has become an essential component within the study of GI. In the end, the potential benefits of GI-related co-creation form the core theme of the dissertation.

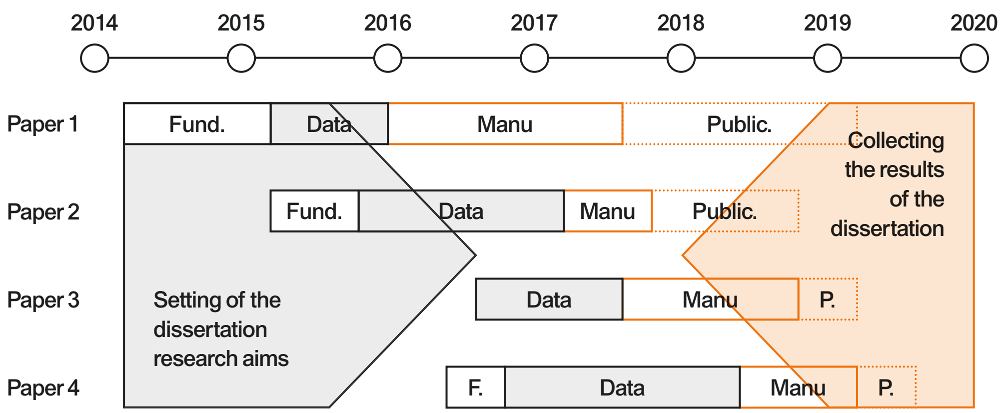

Fig 2. The timeline of the research process, consisting of four research papers (Fund: funding, Data: data production, Manu: preparation of the manuscript, Public: publication process).

The dissertation consists of five chapters. The introduction chapter describes the approach to the topic and the structure of the dissertation, and the research aims and questions are formulated. The second chapter presents the theoretical foundation of sustainable urban development, especially regarding the potential contributions of the urban green and water systems. Subsequently, the methodological approach of the research is introduced, after which the data produced with the help of the co-creation model and the analysis methods used in each paper are presented and justified. The reliability and validity of the research are then considered. The fourth chapter includes a summary of the research papers and the main results concerning the overarching research aims of the dissertation. Finally, in Chapter 5, the scientific influence of the dissertation is discussed, and recommendations for further research are presented.

The significance of the research is that it reveals the importance of co-creation within landscape and urban planning and design as an essential approach to foster mutual capacity building and interdisciplinary learning, especially concerning socio-natural processes. In this context, co-creation accelerates a possible transition towards more adaptive governance models and a more sustainable future.

2 THEORETICAL BACKGROUND

This chapter positions the thesis within the context of the current relationships between humans and nature and the evolution of the concept of sustainability, where GI can play a pivotal and strategic role. In the first section of this chapter, the GI concept is defined more precisely as it relates to the dissertation aims and the model of co-creation. Thereafter, the relationship between humans and nature is presented as the background for the development of the GI-based approach. The relationship between humans and nature has been debated and defined throughout history in the areas of arts, philosophy, and politics. Given the emergence of local, and more recently global, environmental problems, a more sustainable approach towards nature and ecological processes is needed. The evolution of the concept of sustainability is briefly described in this chapter to promote the understanding of GI and its significance as a part of this process.

2.1 Green Infrastructure

In the European policy framework, GI has been defined as ‘a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services’ in both rural and urban settings (European Commission, 2013, p. 3). Moreover, ‘GI is an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife’ (Benedict and McMahon, 2006).

The theory and application of GI have increased substantially during the 21st century (Mell, 2019; Wright, 2011) and are ‘advocated as a means to enhance ecosystem services [ESs] provision via spatial planning’ (Lennon and Scott, 2014, p. 564). Despite its popularity, GI remains a broad concept in terms of appropriate scale (from the national level to local projects) and purpose (including multifunctionality, connectivity, and collaborative planning; Hansen and Pauleit, 2014), challenging exact definitions and solid implementation.

In this thesis, the term *GI-based approach* is used to refer to a strategic approach that addresses the understanding and development of an interconnected network of *GI elements* that maintain ecological processes and functions. A GI element can be a natural or human-made biological structure or component, such as an entire waterway, wetland, or woodland outside densely built urban areas or a park, meadow, green roof, rain garden, or single plant located within the urban fabric that provides ESs, a concept that is closely related to GI.

Moreover, ESs are benefits people obtain from nature (Millennium Ecosystem Assessment, 2005) that are delivered by well-functioning biological structures and processes according to the *cascade model* (Potschin and Haines-Young, 2011; Fig. 3). Complex social and ecological factors and their interactions create and alter ESs (Reyers et al., 2013). As we grow in our understanding of our influence on ES delivery and, indirectly, on our well-being, we can govern our effects by setting policy targets, developing indicators, and establishing monitoring programmes.

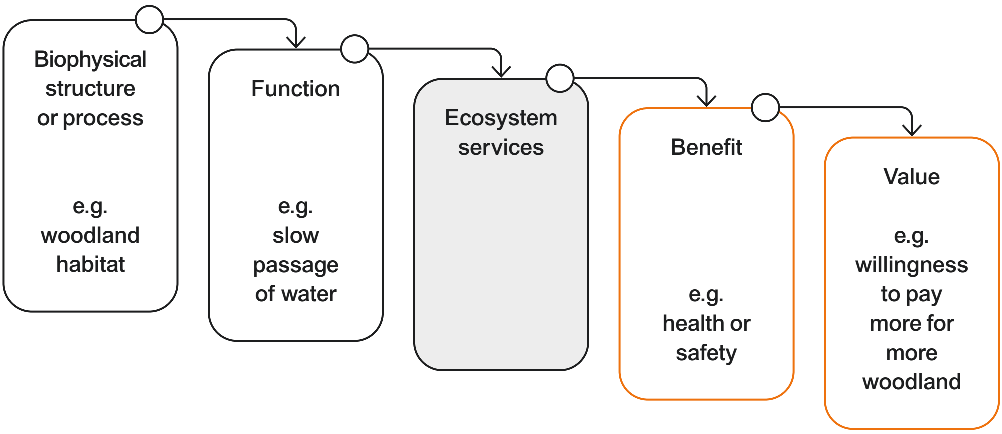

Fig. 3 The ecosystem service cascade model (adapted from Potschin and Haines-Young, 2011).

The 25 defined ESs are grouped into three main categories (Common International Classification of ESs, 2008; Fig. 4). Typically, cultural and provisioning services are well understood and, to some extent, are considered in urban planning, whereas regulating and maintenance services are less well known. However, they have an important role because they are associated with ecosystem processes that maintain environmental conditions that are favourable to life. Among the most important of these processes are cycling substances and ensuring the reproduction of organisms.

Today, the ES concept is resolutely situated within academic and practice debates on how to more accurately consider the value of environmental resources in decision-making (Apitz, 2013). The ES concept shifts the approach from conservation-oriented nature relationships to utility-oriented relationships.

> *Therefore, in defining what the 'significant' functions of an ecosystem are and what constitutes an 'ecosystem service', an understanding of spatial context (geographical location), societal choices and values (both monetary and non-monetary) is as important as knowledge about the structure and dynamics of ecological systems themselves. (Haines-Young and Potschin, 2010, p. 116)*

The comprehensiveness of the ES concept can help us shift away from managing natural resources one by one and treating the environment as an externality. Lennon and Scott (2014) suggested that, if we understand the complex interactions between space and society, we can restructure and realign purposes of spatial planning to facilitate mutually beneficial relations between humanity and the environment. Planning has the potential to contribute to the fluent provision of ESs and a transition to more resilient places that are able to cope with complex environmental disturbances. More precisely, GI has emerged as a concept that may be employed to operationalise an ES-based approach within spatial planning policies and practices. Characterised by multifunctionality and connectivity, the GI-based approach emphasises enhancing and restoring natural assets and designing and creating new natural assets, in addition to the traditional protection of nature (European Environment Agency, 2011).

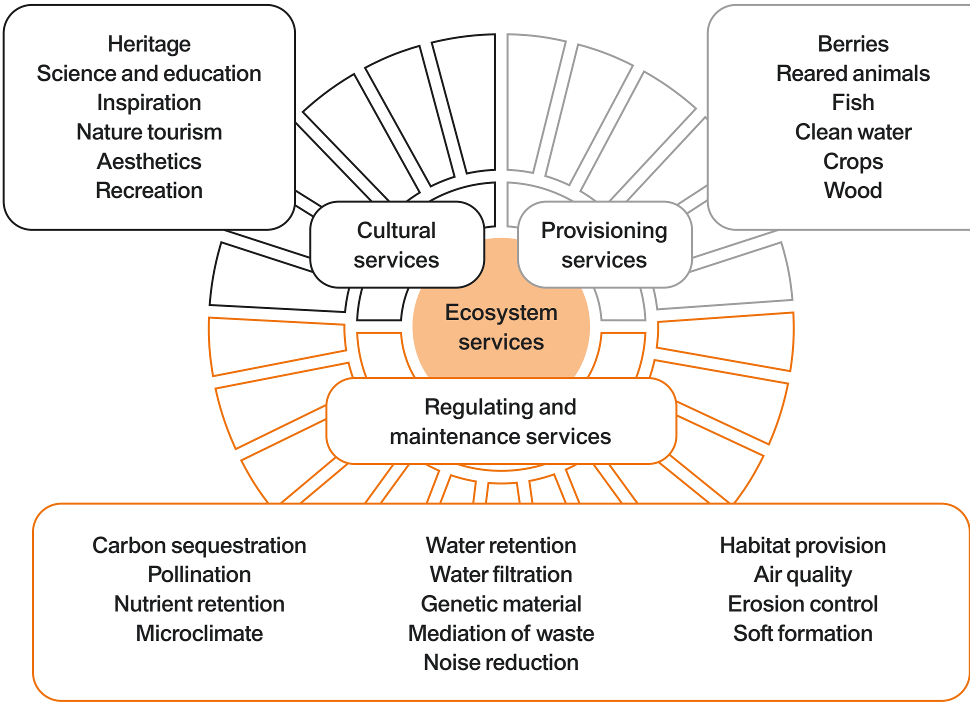

Fig. 4 Three main categories and 25 separate ecosystem services defined by Common International Classification of ESs (2008).

The maintenance and restoration of land-based ecosystems are key strategies to provide ESs and meet the local ES demand. This approach creates new requirements for urban areas, as each climate zone, each region, and each ecosystem requires a customised solution. Acknowledgement of the complex interactions between local circumstances and related societal demands challenges the existing means and purposes of spatial planning to facilitate an adequate GI network and mutually beneficial relations between humans and the environment (Davoudi, 2012; Wilkinson, 2012).

2.2 Green Infrastructure and Urban Water Systems

The GI-based approach can have clear synergies with sustainable urban water management, although urban water management has been traditionally disconnected from urban landscape planning. Brown et al. (2009) investigated the relationship between urban development and water management, showing that human needs (i.e. ‘cumulative socio-political drivers’) have promoted a shift in the development of water-related infrastructure from water supply systems to water sensitivity (Fig. 5).

This development has led to closer connections between water management and landscape planning. Over the last few decades, the decentralised, on-source approach has been a new paradigm in urban stormwater management (Marsalek and Chocat, 2002). Previously, urban drainage was considered only a problem, but related opportunities, such as increased biodiversity and climate adaptation, are now widely recognised (Ashley et al., 2013). This type of approach emphasises the use of multifunctional source controls, the transition from traditional drainage to a GI-based approach, and the consideration of additional environmental benefits (Mailhot and Duchence, 2010).

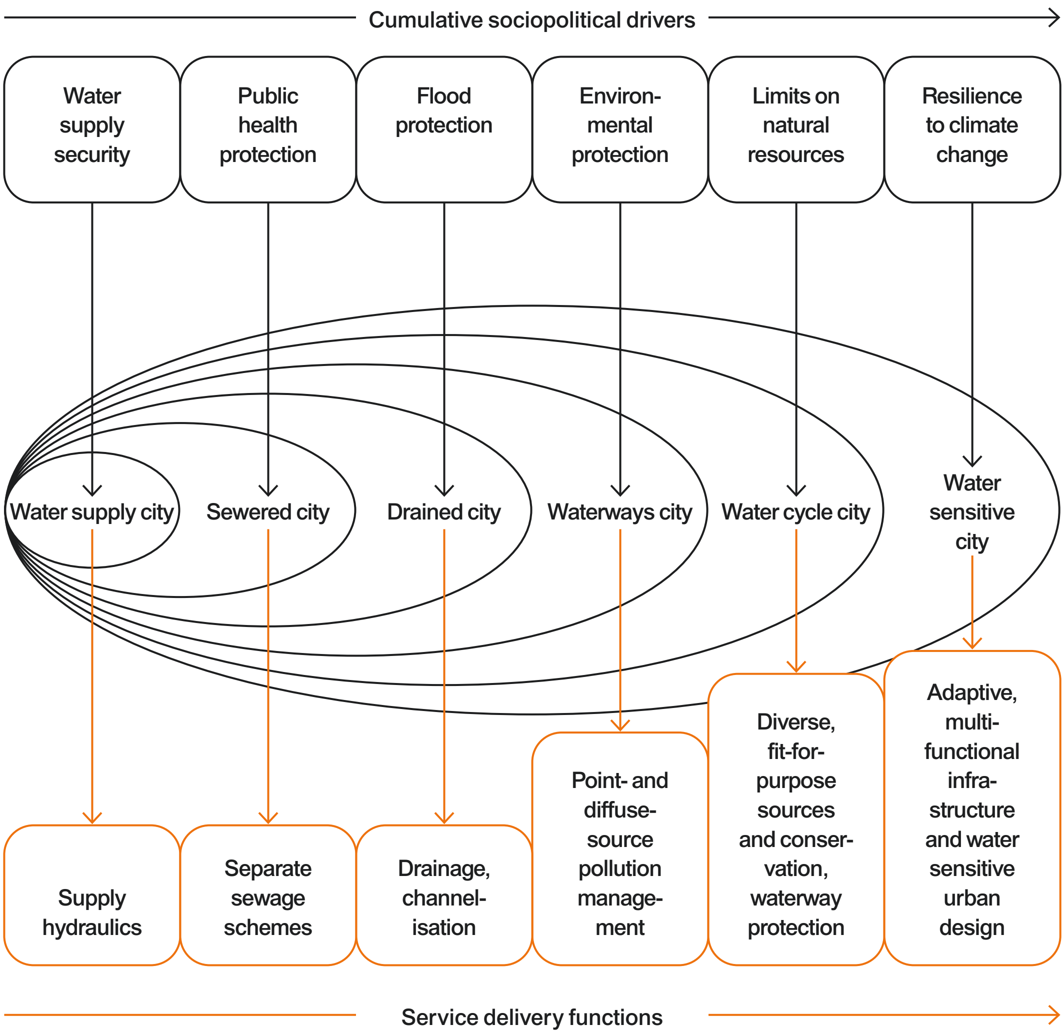

Fig. 5 The evolution of an urban water management paradigm (adapted from Brown et al., 2009).

SUDS are practical applications of the GI-based approach. They use natural processes (infiltration, evapotranspiration, filtration, retention, and reuse) to mimic the natural water cycle of a site. In different contexts, these practices can be referred to by other similar terms (Fletcher et al., 2015), such as low-impact development (LID), best management practices, and water-sensitive urban design (WSUD). Some of the approaches are more strategic (e.g. WSUD), some heavily emphasise water quality and quantity management (i.e. LID), and others emphasise the provision of ESs. In this thesis, the term SUDS is used to describe all kinds of sustainable urban drainage applications to sustain the existing local hydrology that harvest, infiltrate, slow, store, convey, and treat surface water in ways that differ from mainstream, conventional drainage practices.

If the functionality and potential benefits of SUDS are correctly understood, it is possible to create comprehensive treatment trains, a combination of multiple complementary SUDS elements designed to meet the needs of a local environment to achieve better overall quality and quantity management (Revitt et al., 2014). In addition, SUDS can create substantial amenity, recreational, and identity benefits, among other ESs (Haase, 2015; Demuzere et al., 2014; Scholz, 2014), thus connecting water management to the urban green network as an essential part of the urban GI.

Nature-based solutions (NBSs) are also embedded in the SUDS concept, but the term generally refers to a larger set of applications that are comparable to GI elements (Dushkova and Haase, 2020). The NBSs are interventions based on nature that are envisaged to address sustainability challenges, such as resource shortages, floods, health risks, and ecosystem degradation caused by the processes of urbanisation and climate change (Dorst et al., 2019). Moreover, an NBS 'includes the main ideas of green and blue infrastructure, ecosystem services, and biomimicry concepts' and enhances urban regeneration, especially highlighting climate change adaptation and mitigation (Dushkova and Haase, 2020, p. 1).

In general, NBSs and SUDS with urban water management reveal one of the main advantages of the GI-based approach, multifunctionality, which is defined as the ability of GI to 'perform several functions and provide several benefits on the same spatial area' (European Environment Agency, 2012). Additionally, it has been described as the capacity of GI to provide multiple ESs (Liquete et al., 2015). Multifunctionality has subsequently crystallised as a key criterion in determining the quality of an urban landscape (Hansen and Pauleit, 2014; Hansen et al., 2015) and is considered a basic attribute of urban environments that allows them to respond to different challenges and maintain the quality of life (Wang and Banzhaf, 2018). Therefore, multifunctionality is a quality or characteristic that should be incorporated in urban planning and design processes, but operationalisation and practical examples are still lacking (Hansen et al., 2019).

2.3 Sustainable Development

From a broader perspective, the emergence of the GI-based approach can be considered a consequence of the redefinition of the relationship between humans and nature, similar to the way that SUDS, as a part of the water management infrastructure, reflects the development of a new urban and water relationship (Fig. 5). The evolution of the relationship between humans and nature is briefly described in the next two paragraphs and frames the GI-based approach as an essential part of sustainable urban development.

The conventional dichotomist approach claims that nature exists independently of society (White et al., 2016; Carolan, 2005), and this worldview has dominated Western history (Descola and Palsson, 1996). This worldview has been supported by religious assumptions that perceive humans as the crowning glory of God's creation with the development of capitalism, the industrial revolution, and modern science (Hopwood et al., 2005). For example, the *Oxford English Dictionary* (2019) defines *nature* as 'the phenomena of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth, as opposed to humans or human creations'.

Currently, natural and human societies are understood as being intertwined and interacting (White et al., 2016). Our actions affect the natural world, and biophysical and ecological processes can simultaneously play an important role in shaping social conditions. However, it has taken some time to reach this understanding (Carolan, 2005), as clarified in the following paragraphs.

Nature consists of ecosystems that are the result of interacting organisms and their physical environments. Ecological processes sustain all ecosystems, keeping them alive and functioning, and they are connected, according to Alexander Von Humboldt (Wulf, 2015). Von Humboldt was an 18th-century scientist and explorer who claimed that the world is a single interconnected system in which ecological processes have produced diverse ecosystems and related biological communities over millions of years. Thus, he understood that nature is a huge, complex system.

It took 100 years more to fully and scientifically understand that humans are part of that system. In the mid-19th century, George Perkins Marsh was the first to declare that the actions of humankind disturb and threaten existing ecosystems (MacKinnon, 2013). Marsh showed that ancient human civilisations left their mark on the landscape and that their rise and fall were both related to natural resources and the overconsumption of them.

During the 20th century, the effects of industrialisation, consumerism, and the growing population have become more evident. Roots of the environmental and sustainability movements have their origin in the 1960s when the first environmental science books, such as Rachel Carson's *Silent Spring* (1962), were published, and the adverse environmental effects caused by human actions were questioned for the first time. Environmental threat analysis started the development of both environmental policy strategies and environmental legislation, and the United Nations (UN) held its first environmental conference in 1972. During the same year, the concept of *sustainability* was introduced in the publication *The Limits of Growth* (Meadows et al., 1972).

However, the real breakthrough for the concept *sustainable development* was the 1987 book *Our Common Future* by the Brundtland Commission (World Commission on Environment and Development, 1987). This book was also 'the first overview of the globe, which considered the environmental aspects of development from an economic, social and political perspective', thus entwining social and ecological aspects more tightly together (Redclift, 2015, p. 212). Although the book warned of international environmental problems and criticised industrialised countries, it saw economic development as still desirable; thus, the concept of sustainable development moved from the margins to the mainstream (Wheeler, 1998).

Numerous definitions exist for *sustainability* and *sustainable development* that depend on the changing cultural constructions placed on the environment (Redclift, 2005). Accordingly, no single unified philosophy of sustainable development exists (Hopwood et al., 2005). The more recent awareness of large, persistent changes (Rocha et al., 2015), such as species extinction, increased pollution, and lack of resources, has prompted the development of various policies that attempt to guide us towards sustainable development (e.g. World Summit on Sustainable Development, 2002; Transforming our World: The 2030 Agenda for Sustainable Development, 2015; Steffen et al., 2015).

Furthermore, escalating climate change and biodiversity loss both indicate that complex social and ecological interactions have resulted in increased exposure to new types of risk (Helbing, 2013), generating new demands for sustainable development. Inherent in the concept of sustainable development is the idea that society needs to change, although our conceptions of the scale, tools, and actors associated with the change vary from moderate status quo views to radical transformative views (Hopwood et al., 2005). However, the demands for a more comprehensive transformation and a systemic approach have recently increased as people gain new comprehension of the magnitude, frequency, and consequences of environmental changes caused by humans (Reyers et al., 2018).

2.4 Sustainability and Systems Thinking

Increased understanding of our effects on the planet and of what kind of ecological feedback loops are generated by our social and economic actions has resulted in the definition of the *Anthropocene*, a new geological era. The Anthropocene has been defined as the age of humans (Reyers et al., 2018), and various views exist on its precise starting point, but 'there is no doubt that, since the middle of the 20th century, human beings have exerted enormous pressure on some of the most crucial bio-geo-chemical cycles' (da Veiga, 2017, p. 235) at such a large scale that it is now threatening our well-being. Escalating environmental changes interact and connect across scales with great social and economic consequences and turbulence, triggering feedback loops (Steffen et al., 2011).

With the increasing understanding that the biosphere is in a constant state of change and that those changes and the associated processes can play key roles in shaping human societies, the interest in resilience has grown. *Resilience* is a concept that comes from natural science, referring to the ability of a system to absorb disturbances and retain its basic function and structure (Walker and Salt, 2006). The response of any system to shocks and disturbances depends on its context, connections across scales, and current state. Resiliency is the capacity of a system to undergo change and retain essentially the same function, structure, and feedback.

In the context of sustainable development, resilience is linked to adaptive strategies to cope with and adapt to changes and the *socio-ecological system* (SES) approach (Reyers et al., 2018; Folke, 2016). According to the SES approach, all individuals, communities, and societies operate in social systems that are embedded in the biosphere and ecological systems; thus, humans all exist within SESs. Moreover, SESs are complex adaptive systems, where sustainable development requires 'finding ways for people and institutions to govern social-ecological dynamics for improved human well-being, at the local, across levels and scales, to the global' (Folke, 2016, p. 1). Sustainable development requires *systems thinking*, which must be based on the appreciation of the intertwined nature of the environment and society with feedback loops operating in both directions.

2.5 Urban Development and Sustainability

Urban development has followed the changing needs of human societies, and sustainability is no exception to this trend. As over half of the human population is currently living in urban areas that shape external ecosystems and depend on them for water, food, and other ESs, urbanisation is a major driver of the Anthropocene (Barau and Ludin, 2012). Furthermore, urban areas can be considered interlinked SESs that are complex and adaptive (Sellberg et al., 2015). Thus, *sustainable urban development* is necessary and can support our attempts to live in a more balanced way with ecological processes.

Sustainable urban development can encompass various efforts: attempts to build a smart information society, to establish friendly and liveable communities, to reduce carbon footprints, and to promote balanced ecological development through GI (Jong et al., 2015). In discussions and political initiatives, these efforts are often linked together, and related concepts overlap and even mix. The term *sustainable city* is an umbrella category that gathers ideas about how 'comprehensive human-supported technological interventions benefit social well-being, economic growth and ecological regeneration in the city' (Jong et al., 2015, p. 26).

In contrast, the concept of a *resilient city* is related to safety science, environmental science, and governance. In this research, *resilient city* refers to *adaptive governance*, a regime that increases positive interactions between a city and its natural environment, especially regarding ES provision. In doing so, the adaptive governance involves a transformation in the ways urban planning systems are approached and how practitioners conceive of their influence on urban SESs.

Consequently, adaptive governance is the practical embodiment of the resiliency approach. Both social and ecological systems are complex systems, and SES governance requires insight into their coevolution. According to Assche et al. (2019), critical requirements for adaptive governance include constant learning and allowing both experts and local knowledge to influence decision-making to manage the couplings between systems. The management of these couplings makes the social and ecological systems more, less, or differently responsive to each other and modifies their effects on each other. New governance configurations are necessary, both enabling and embodying veried couplings between social systems or between social and ecological systems (Assche et al., 2019). Regime shifts to policy interventions, targets, and adaptive management that acknowledge and are based on the system's irreducible complex structure are proposed for sustaining desirable system outcomes.

Following this need to reassess linkages between social, ecological, and planning systems, Lennon and Scott (2014, p. 569) identified an ecological fix, a transition in landscape and urban planning processes and practices to 'fully integrate the ecological dimension alongside traditional planning concerns'. GI is perceived as a concept that can deliver socio-ecological integration and allow humans to work towards alignment with nature. Similarly, Ahern (2007) stated that the implementation of urban GI is essential to achieving a regime shift, placing ES provisions and environmental risks as central concerns of urban planning.

From the SES perspective, resilience also includes the capacity of the system to transform with change. Transformability is the capacity of an SES to learn, combine experience and knowledge, and adjust its responses to changing external drivers and internal processes (Folke, 2006). The resilience approach allows the new identity of an SES to emerge through interactions of individuals, communities, and societies through their interplay with the biosphere within and across scales (Folke et al., 2010). Living with such complexity and change is facilitated by co-creation and adaptive approaches. Therefore, it seems essential to further test the potential of co-creation to promote the GI-based approach and study what kind of additional implementation is needed to strengthen the contribution of GI.

2.6 The Need for Co-creation

The implementation of the GI-based approach is complex, beleaguered by uncertainties (Lennon et al., 2017), and often hindered by social, organisational, or political barriers, including a silo mentality (Kambites and Owen, 2006). Earlier studies have shown that the interaction of research and practice improves the use of scientific knowledge (Arnott et al., 2020) and the involvement of multiple participants in producing new ways to integrate knowledge into decision-making and action (Wyborn et al., 2019).

The need for multidisciplinary co-creative processes has been brought to the attention of the landscape and urban planning community as a means of sharing learning and the understanding of GI (Lennon et al., 2016; Faehnle et al., 2014; Ahern et al., 2014;

Kopperoinen et al., 2014; Lafortezza et al., 2013). To solve complex environmental problems, we need new types of collaboration (O'Brien, 2012; Mauser et al., 2013; Wyborn et al., 2019). In addition, professional silos and the lack of a collaborative approach have been identified as two of the main barriers that limit the adoption of GI (Lennon et al., 2016; Ahern et al., 2014; Mell, 2010). Moreover, knowledge-related barriers could be lowered by promoting collaboration with different stakeholders (O'Donnell et al., 2017).

In this context, researchers serve as facilitators when collaborating with planners and local governments in outlining policies and programmes for the development of GI (Hostetler et al., 2011). Co-creation should involve a wider range of stakeholders in landscape and urban planning, landscape architecture, ecology, architecture, and urban design (Ahern et al., 2014).

It is also important to understand that the introduction of GI to several disciplines, such as landscape architecture, landscape planning, urban planning, engineering, and urban design, does not occur straightforwardly. Professional, cultural, planning, and political contexts exist in which new GI knowledge is challenged by the status quo of expertise (Di Marino and Lapintie, 2018).

Our understanding of ESs delivered by urban green structures is still limited because nature is valued primarily for recreation or limited-use habitat conservation (Lennon and Scott, 2014). Additionally, practitioners do not yet possess a clear understanding of what constitutes GI, or they are confused by the complexity and ambiguity of the concept (Wright, 2011). Thus, GI cannot be implemented as a top-down strategic planning approach, but new forms of interaction must be explored between stakeholders and inside professional collaborations. To achieve GI's potential, practitioners need to comprehend how the approach is implemented in practice (Wright, 2011).

Collaborative processes have become a cornerstone of research to achieve new sustainability-related knowledge and implement its findings: collaboration brings scientific and practical knowledge together with a wide range of relevant stakeholders and can lead to societal change (Wyborn et al., 2019). Collaboration among diverse actors can help to develop common ground and mutual understanding. Furthermore, it can create new capacities to integrate science with enhanced engagement of stakeholders (van Kerkhoff and Lebel, 2015).

In this research, capacity is regarded as a relevant outcome of the co-creation process. Capacity can be defined as '… the ability to perform functions, solve problems, and set and achieve objectives' (Fukuda-Parr et al., 2003, p. 8) on three levels: the systems level, the institutional level and the individual level (UNDP, 1998). Furthermore, van Kerkhoff and Lebel (2015) emphasize capacities to create, access, interpret, and apply scientific and research-based knowledge along with capacities to combine science with existing, localized knowledge, practices, and governance as responses to global environmental change.

However, from the researcher's perspective, difficulties still exist in providing notions and tools that are adequate for the implementation of GI through co-creation. While collaborative processes have been identified as effective strategies to implement new knowledge about planning (Opdam, 2010; Lennon et al., 2016), they have also been criticised for offering little clarity on process objectives and outcomes (van der Jagt et al., 2019), for lacking evidence supporting claims of impact (Lemos et al., 2018), for involving overly local orientation (Sutherland et al., 2017), or for reinforcing the power of policy elites or those who have the time and capacity to engage, thereby marginalizing those with alternative perspectives (Lövbrand 2011; Turnhout et al., 2020).

In this research, the model of co-creation (Fig. 6) proposed by Mauser et al. (2013) is used to frame collaborative actions between stakeholders. The model is a tool to introduce 'new research strategies, with a strong focus on joint efforts by researchers from the natural, social and human sciences and engineering to contribute' to a globally sustainable future (Mauser et al., 2013, p. 421).

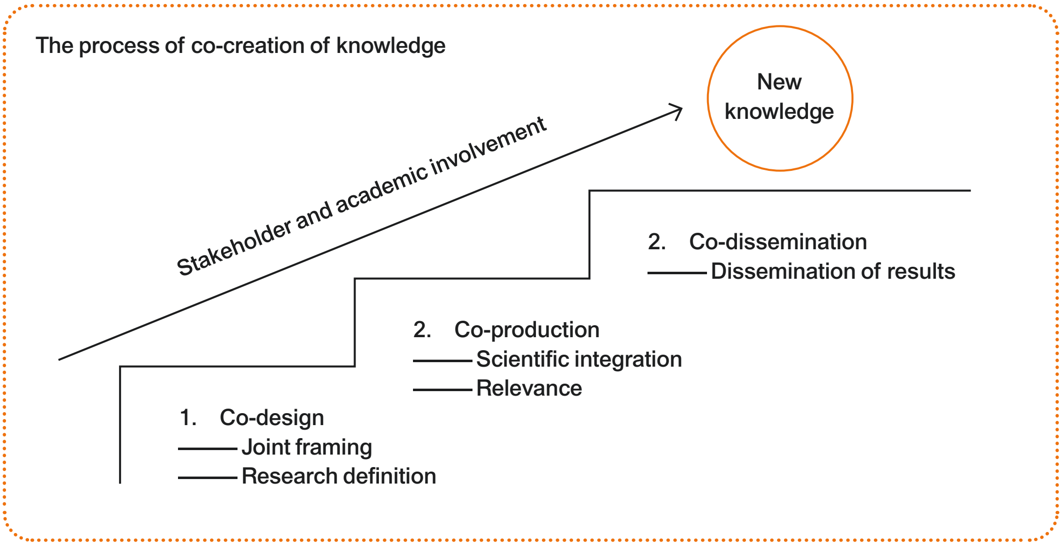

Fig. 6 The steps of knowledge co-creation (adapted from Mauser et al., 2013).

The model introduces three steps of the research process, identified as follows:

1) *co-framing* (originally *co-design*, but renamed here to bring clarity to process descriptions in Chapter 3), where the research aims and questions are framed in collaboration with different research stakeholders;
2) *co-production*, where integrated research (or the planning or design processes as discussed in Papers 1, 2, and 3) is conducted as a continuous exchange and communication process among the participating research group and other stakeholders; and
3) *co-dissemination*, where the results are translated into comprehensible and usable information for various stakeholders, and an open discussion occurs on the valuation, applicability, and relevance of the results.

The use of the model is explained in more detail in Section 3.2. (Co-creation of Knowledge).

3

METHODOLOGY

3.1 General Methodological Approach

An action research case-study strategy was chosen as the methodological approach for this study to investigate what kind of results GI-related co-creation can deliver for sustainable urban planning and design processes (Deming and Swaffield, 2011). The background and use of the methodological approach are covered in this chapter. The epistemological position of the research is social-constructionist, presuming that the knowledge addressed in this dissertation is generated through experimental learning and is actively constructed by stakeholders internally and between one another (Crotty, 1998); thus, the knowledge is aligned with the use of the co-creation model (Mauser et al., 2013). This knowledge is nonetheless anchored in a world that exists beyond the subjectivity of an individual or group of individuals (Deming and Swaffield, 2011).

The research is in the field of landscape architecture and focuses on developing, planning, and managing new landscape architectural solutions for GI. In the larger framework, the research belongs to sustainability sciences at the intersection of social and environmental sciences involving the interaction of human and biophysical relationships. The case-study strategy has been chosen to investigate 'a contemporary phenomenon [GI in this research] in depth and within its real-world context' (Yin, 2014, p. 16).

Case-study methods are popular among urban researchers (Campbell, 2003) because the benefits of the case-study approach are well suited for urban contexts. Case studies are used in research situations when there is a difficulty in separating the phenomenon from its larger context, there is a little control over events, and the aim is to seek cause–effect understanding to guide contemporary intervention (Yin, 2014). These elements are characteristic of urban research that is seeking cause–effect understanding to guide planning intervention.

The urban research field also generally lacks the power and resources to test theories using controlled experimentation. Furthermore, urban research is not defined by a clear set of methods and does not have a dedicated set of data but instead uses multiple sources of evidence (such as data, interviews, and observation). Therefore, 'a case study can more flexibly represent the varied and conflicting voices of the city than a traditional statistical summary' (Campbell, 2003, p. 4). As urban research settings are composed of complex networks of social, economic, and political activity, case studies are more effective tools than statistical analyses to define best practices that can help to guide planning practices (Campbell, 2003).

In this research, each paper includes one or more real-life cases that have been the subject of empirical inquiry and data collection. Replication logic of the study has been to include only Finnish case studies with similar planning principles derived from national planning policies that represent advanced and actual urban situations dealing with GI. In three papers (Papers 1, 3, and 4), the case is a physical place where GI solutions are adopted, and in the second paper, the case is a development of a policy paper on the adoption of GI solutions (the city of Helsinki stormwater programme). In addition, two cases (Papers 1 and 2) consider the planning level and the other two cases (Papers 3 and 4) the design level in order to cover both the more strategic (planning) and the more concrete (design) stages of GI development.

Case-study methods are sometimes questioned because of the related replication challenges: cases are more appropriate for proving that something is possible than for revealing its precise likelihood (Campbell, 2003). The research cases have been meticulously selected based on critical analyses of existing situations to answer the research questions (1. to understand how to co-create GI within landscape and urban planning and design in Finland and 2. to determine what kind of further implementation is needed to strengthen the contribution of GI), which do not aim to generalise but rather to advance existing planning practices through case narratives.

The three cities in Paper 1 (Jyväskylä, Tampere, and Vantaa) were identified as having a growing interest in developing local GI strategies and practices within the built environment. The cities had several ongoing and future pilot projects concerning the use of green roofs, storm water detention, and biofiltration within the urban area (such as the Kangas district in Jyväskylä, the residential area of Vuores in Tampere, and stormwater pilots in Vantaa). For the co-creation process, each city was asked to select an urban area that was already planned for new development. The three sites were selected for the paper because of the growing interests of local policy-makers, city planners, and other stakeholders in developing GI strategies and initiating GI pilot projects.

The city of Helsinki, sites of the cases in Papers 2 and 3, is the biggest city in Finland and is part of the capital metropolitan region. It has a claim to be facing the most intensive urban environmental challenges in Finland. Climate change mitigation is of primary importance in the region, and the metropolitan area is aiming to be a forerunner in climate change adaptation (HSY, 2012). Furthermore, Helsinki was the first city in Finland to develop a stormwater strategy (2008), which has been used in other Finnish cities (Salminen, 2013). Paper 2 uses the process of revising the Helsinki stormwater programme as a case for studying barriers to shifting towards water-sensitive practices. Paper 3 focuses on the process of designing a new GI solution, the Vauhtitie wetland, which implements stormwater and climate adaptation strategies.

The city of Turku has been ambitious with its climate policies and has been chosen as the Best Mid-sized Climate City in Europe for 2020. Turku is implementing an ambitious climate plan, of which one of the main goals is to prepare for the impacts of climate change. The primary pilot site for climate adaptation in Turku is the Kirstinpuisto area, a former industrial site that will be transformed into a residential site. The Kirstinpuisto area's multifunctional stormwater management scenarios form the case in Paper 4. Practical stormwater management with the help of SUDS is a current topic in Finnish urban planning, and the Turku case is a representative situation in which the city centre is being densified and therefore, a brownfield is being transformed for residential use.

3.2 Co-creation of Knowledge

The constructionist epistemological approach and the use of an action research case-study strategy with the definition of specific additional aims led to the selection of specific research methods in each case study (Fig. 7). Thus, the methods used for data collection and analyses vary to some degree from paper to paper while having a common grounding in *action research* (Deming and Swaffield, 2011). Action research involves actively participating in a process or situation under study. The starting point is practical action, in which the researcher takes part and affects the process while using scientifically recorded observations to provide data for analysis. As the aim of the research is not only to produce new knowledge but also to facilitate a transformation to a better urban system than the existing one, a more effective way to work with cases is to use the co-creation model (Mauser et al., 2013; Deming and Swaffield, 2011).

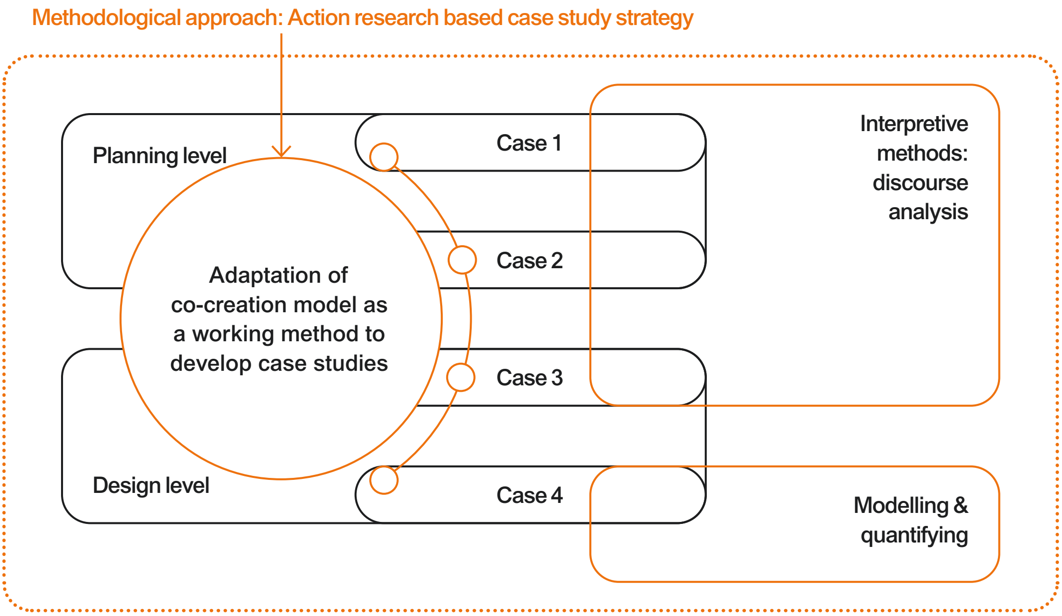

Fig. 7 The selected methodological approach and specific research methods of the dissertation and their relation to the co-creation model (adapted from Mauser et al., 2013).

As described in Chapter 2, GI is part of an emerging approach to integrating human and biophysical processes to deliver more sustainable planning and land-use practices. Moreover, GI-related literature emphasises the need for cross-sectoral collaboration and mutual learning to implement GI planning (Lennon et al., 2016; Ahern et al., 2014; Mell, 2010). Therefore, the conducted research was inherently considered an opportunity not only to find answers to research questions regarding existing GI practices but also to enhance the adoption of the GI-based approach in co-creative processes. In each case, the doctoral candidate was involved in the process of data production. The ways in which the doctoral candidate and other research group members participated in each of the case studies are comprehensively described in Sections 3.4–3.7, and the challenges of this approach in terms of the reliability and validity of the results are discussed in Section 3.3.

The co-creation model presented in Section 2.3 was employed to integrate a GI-based approach into the case studies, which are closely connected to real-life landscape architectural projects. The focus of the research is on the planning processes developed in the case studies (Papers 1, 2, and 3) or the characteristics of the design outcomes (Paper 4), thus the data collection method is linked to action research. The data collection processes and specific research questions for each paper are detailed in Sections 3.4–3.7, but first, both the use of the co-creation concept and the paper-specific research methods are explained in the following section.

Co-creation is a research method that has its roots in participatory design techniques that enable a wide range of stakeholders to contribute to the formulation of a case (Steen et al., 2011). Co-creation goes beyond the delivery of scientific evidence by deepening the equal collaboration between stakeholders and enabling mutual learning and the co-production of results (Mauser et al., 2013). Partnering with stakeholders ensures their inclusion in knowledge development in a process that can serve these same stakeholders (Opdam, 2010), thus making co-creation ideal for promoting a GI-based approach in urban planning and design processes.

3.3 Analysis Methods

The collected data were analysed using two primary research methods: content analysis (Papers 1, 2, and 3) and modelling with quantitative measuring (Paper 4). *Content analysis* is a method in which the understanding of a certain phenomenon or process is produced by moving reflexively between the data and the existing theoretical concepts (Deming and Swaffield, 2011) and can be defined as ‘a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use’ (Krippendorff, 2004, p. 18). Qualitative content analysis has a focus on analysing the content of a given text or texts and identifying the dominant narratives they contain. The aim is to create a picture of a given phenomenon that is always embedded within a particular context (White and Marsh, 2006).

In this dissertation, the content analysis method is used to better understand how GI, as a novel concept, has been understood and adopted and what difficulties have occurred in these adoption efforts. Furthermore, the method has enabled the doctoral candidate to better understand larger dynamics affecting the urban planning processes and the possible transition to SES thinking. The premise is that we can discuss the possible means and desired outcomes of the shift towards SES thinking in urban planning, and to enhance this shift, we need first to understand the factors affecting it.

In addition to content analysis, *quantitative measuring* was used in Paper 4 to study the multifunctionality of the Kirstinpuisto SUDS as part of the local GI. The methods for the modelling and quantitative measuring of the attributes of the co-produced drainage systems are explained in detail in Paper 4, but these methods were chosen to assess the degree to which the four criteria for multifunctionality set by water sector guidelines were met. Multifunctionality is the main feature of GI solutions (Hansen and Pauleit, 2014; Hansen et al., 2015) and represents one of the predominant promises and challenges of GI. As the desired results of the development project are plentiful, a mutual comparison can be challenging; thus, defining the levels of success is complicated. These issues are also discussed in Paper 3 in analysing the process of designing a new GI element. By quantifying and measuring success against the four criteria for multifunctionality, it is possible to reveal some of the existing development challenges affecting the integration of a GI-based approach to urban planning and design.

In the following section, the data production and collection processes and the analysis methods of the case studies are presented. In addition, the researcher's involvement (action research) in the process is analysed. The results of the case studies (the benefits delivered by co-creation) are presented in Chapter 4, but in the following sections, the steps of the applied co-creation model (co-design, co-production, and co-dissemination, presented in Fig. 6) are elaborated.

The role of the co-creation model (Mauser et al., 2013) is to bring stakeholders together (Papers 1 and 2) and to create opportunities for mutual learning, knowledge co-production, and discussion, forming an area for data production and collection. In Paper 3, data collection occurs through a retrospective analysis of a co-created GI solution, and in Paper 4, the co-creation provides input for the generation of different scenarios, from which the data are collected. Co-dissemination took place through the research papers (included in this doctoral thesis), the site development, and the promotion of new ways of thinking among the participants.

The co-creation process in each case is displayed in a diagram. The main results of all of the papers are presented in Chapter 4.

3.4 Case 1: Understanding Green Infrastructure

In Paper 1, 'Multidisciplinary Collaboration and Understanding of Green Infrastructure: Results from the cities of Tampere, Vantaa and Jyväskylä (Finland)', the aim was to increase the understanding of GI by implementing GI strategies and concrete solutions in three case sites. The paper provides the main findings regarding the use of the GI concept on the planning level and addressed the following research question: How does a multidisciplinary collaboration among practitioners themselves and between practitioners and researchers support the understanding and development of GI within the new urban development? Furthermore, the paper contributes to the dissertation aim of understanding how co-creative processes promote the use of multifunctional GI in sustainable urban planning.

In this case study, co-framing was based on a literature review and the co-definition of the multidisciplinary collaborative process (Ariluoma et al., 2015) to enhance the collaboration of science and practice. The multidisciplinary collaborative process is a model developed by Ariluoma et al. (2015), a group that includes the author of this dissertation, and was articulated through questionnaires, a set of workshops, and homework (see Paper 1 for details). The co-production phase involved 23 official practitioners (architects, landscape architects, engineers, and experts in natural sciences) from three city planning departments and researchers from Aalto University (four landscape architects) in a series of workshops. The workshop series was a tool for cultivating multidisciplinary learning between practitioners from different fields and between practitioners and researchers to develop appropriate GI solutions for three urban planning cases. Data were collected in the workshops and from questionnaires that preceded and followed the workshop series.

In addition to the two above-mentioned workshops, the co-production between the 23 official practitioners and the four researchers included answering pre- and post-questionnaires, reading independently (including scientific and newspaper articles about urban biodiversity, health, and economic benefits), and performing tasks before and between workshops. During the workshops, participants were asked to familiarise themselves with GI elements at different scales and were invited to outline a vision by developing local strategies and plausible actions to introduce GI approaches and elements within the future development of the selected sites (Fig. 8). Furthermore, the planners were asked to detect obstacles and barriers related to GI development and to define new strategies and actions for developing GI within the case sites.

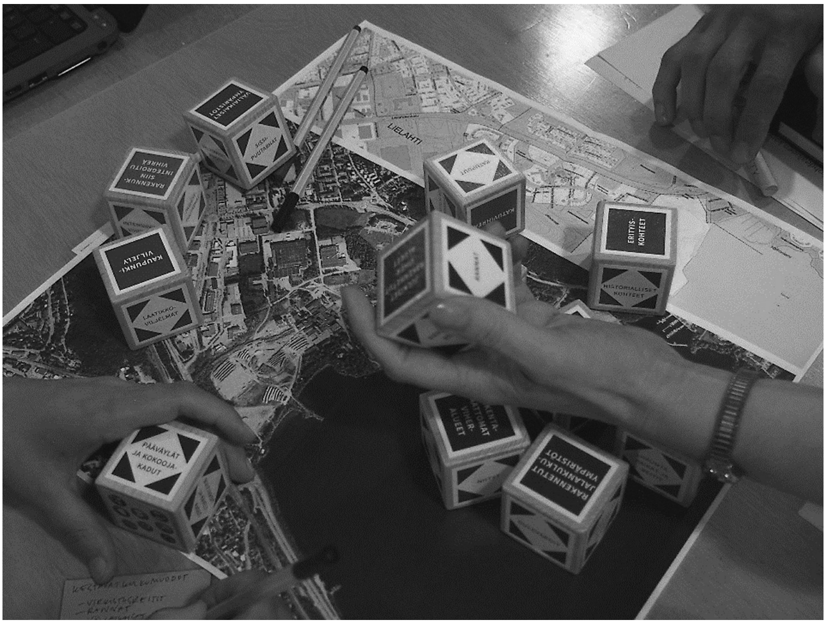

Fig. 8 Photo from the workshop where different kinds of GI elements were introduced to the participants through playful exercises.

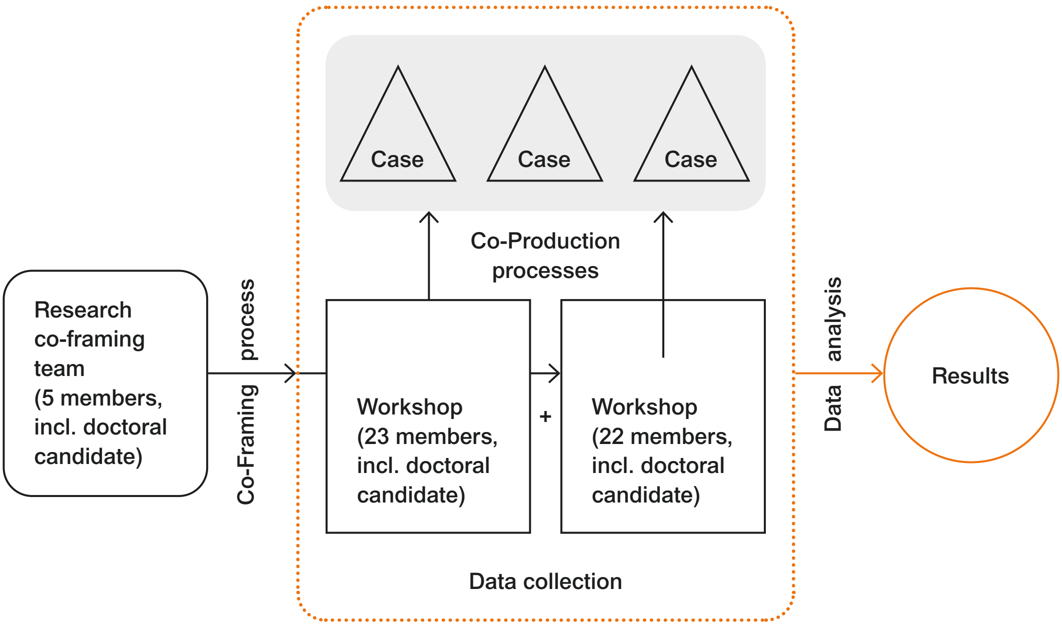

Fig. 9 Data production process of Paper 1. Three case-study sites were developed during a workshop series from which the data were collected. Data were then analysed through content analysis.

The role of the researchers included framing and organising the workshop series and developing the questionnaires participants used to reflect on the learning processes. Additionally, during the workshops, the researchers provided information and actively participated in the discussion by offering scientific knowledge and concrete materials to boost collaborative learning, aid envisioning, and encourage the implementing GI elements within the proposed case sites (Fig. 9).

Collected data included 13 hours of recorded workshop discussions and 22 written definitions of the GI concept, with descriptions of earlier experiences with the subject. The data were analysed to understand how a multidisciplinary collaboration supports the understanding and development of GI within new urban developments. Co-dissemination of the process through a scientific article was performed with Mina di Marino, an associate professor of urban and regional planning, Norwegian University of Life Sciences.

3.5 Case 2: Integrated Stormwater Management

In Paper 2, 'Barriers Preventing Development of Integrated Stormwater Management in Helsinki, Finland', the focus was the current state of understanding regarding water-related GI and existing barriers hindering the more effective use of GI-based approaches. Climate change, urbanisation, and the desire for resource efficiency have led to the search for and development of GI-based SUDS that are alternatives to traditional drainage systems and to a progressive shift towards water sensitivity, as explained in Chapter 2. The paper uses the process of revising the Helsinki stormwater programme as a case to study barriers related to this shift. The specific research questions addressed in this paper are the following:

1) What kind of barriers can stakeholders of public-sector stormwater management identify by themselves regarding the implementation of GI strategies?
2) Which other barriers can be identified?

Identification of the existing barriers helped make clear which technical or administrative changes must be made to promote GI, which, in turn, helped to clarify the conditions required for the effective use of the GI concept in urban planning. Additionally, the results of Paper 2 offer a supplemental understanding of the results of Paper 1 regarding the way co-creative processes promote the use of multifunctional GI.

Relevant data were collected during a co-production workshop, where the goals of the revised stormwater programme of the city of Helsinki were discussed. This workshop was part of the iWater (Integrated Stormwater Management) EU programme, which designed stormwater planning tools and approaches to support higher quality and more resilient urban environments (for more information, visit www.integratedstormwater.eu). Two researchers (the doctoral candidate and a PhD in environmental science) co-framed the working methods for producing data in the framework of the iWater project.

In the workshop, the research data were collected from group discussions on the implementation of the previously mentioned Helsinki Stormwater Program and on defining action points and responsible bodies for its implementation and monitoring. The new programme included four goals (1–4) from the previous program and one new goal (5) that tentatively emphasised the policy level, making the programme more ambitious and holistic (Fig. 10).

As displayed in Fig. 11, the researchers facilitated the co-creation process by framing and organising the workshop with 21 civil servants from the city of Helsinki. The specific role of the researchers was to contribute scientific knowledge to the process and to reflect

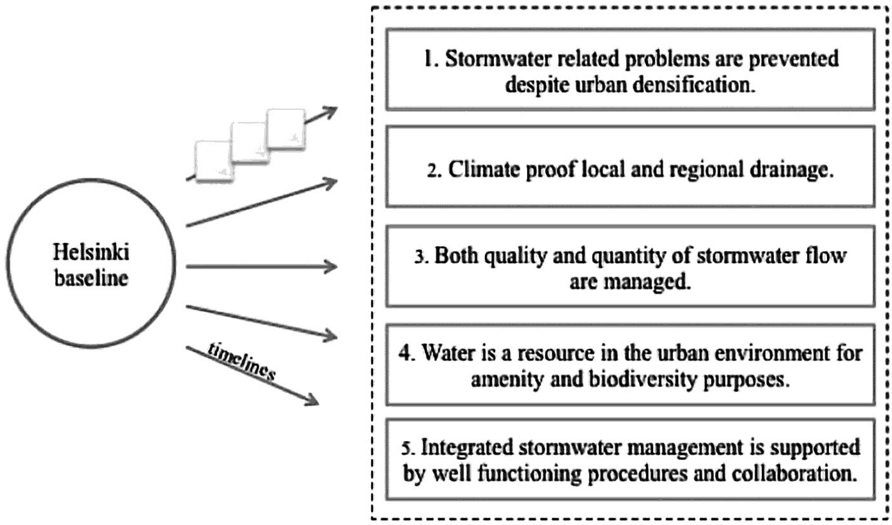

Fig. 10 The programme discussion goals in the workshop. The baseline situation is on the left, and the goals for the new program are on the right. Participants were asked to add Post-it notes with the proposed actions to the timelines drawn from the baseline to each of the goals.

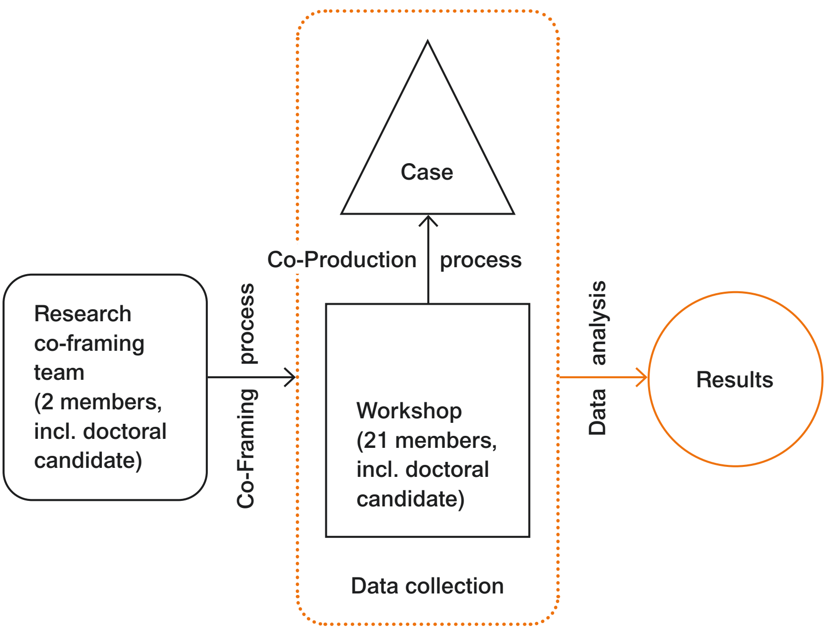

Fig. 11 Data production process of Paper 2. The case is the city of Helsinki stormwater programme developed in a workshop. Data were collected from workshop discussions and analysed using content analysis.

on the definition of goals according to the theoretical literature on the subject. Additionally, researchers participated as members of two of the four groups during the workshop. This participation allowed them to observe the group dynamics and the deliberations and questioning, which supported the subsequent discussions and facilitated the analysis of the recorded conversations.

The collected dataset included 16 hours of recorded discussions dealing with the proposed actions to achieve the revised programme goals, identify the responsible bodies, and prioritise the actions. Data were analysed to reveal distinctive themes that helped identify barriers to the implementation of integrated stormwater management.

3.6 Case 3: Multistakeholder Design Process

Paper 3, 'Multi-stakeholder Cooperation for Green Infrastructure: Creating Sustainable Value', used stakeholder interviews to assess the process of designing a GI solution for the Vauhtitie wetland. The aim was to retrospectively examine how collaboration and decision-making occur in a setting with multiple stakeholders and value perspectives. Furthermore, the study aimed to foster multistakeholder cooperation related to sustainability. The study also searched for specific methods and capabilities for developing common objectives in complex inter-organisational projects and for enhancing decision-making about value creation in the area of sustainability. Thus, this paper offers insight into a secondary aim of this doctoral dissertation: to understand what kinds of benefits knowledge exchange between stakeholders can deliver in terms of defining urban GI.

Fig. 12 The Vauhtitie wetland, a new type of GI structure collecting and managing stormwater from a new urban district of Pasila. Located in a park, it enhances the local biodiversity and recreational value.

Before the actual research process, the doctoral candidate was involved in the wetland design process (Fig. 12) as a consulting landscape architect. The design process consisted of several meetings with civil servants from various departments and with consultants from an engineering company. The process included a location and site analysis, a concept design phase, and a construction design phase. The meetings offered a framework for intensive negotiations regarding the expected outcome and its benefits. Co-production by stakeholders of a shared understanding of multifunctionality and goals proved to be challenging. The study of the design process consequently also contributed to the additional aim of the research: studying how co-creation can inform and support the processes of designing multifunctional GI.

The case study analyses the development of a new type of GI solution, and because the doctoral candidate had insight concerning the design process, the case proved to be a good example of co-creation (Fig. 13). The research was co-framed with another doctoral candidate, Riikka Tapaninaho, from Tampere University (Management Studies). The researchers chose in-depth individual interviews as the research method to conduct a retrospective analysis of different stages and outcomes of the design process.

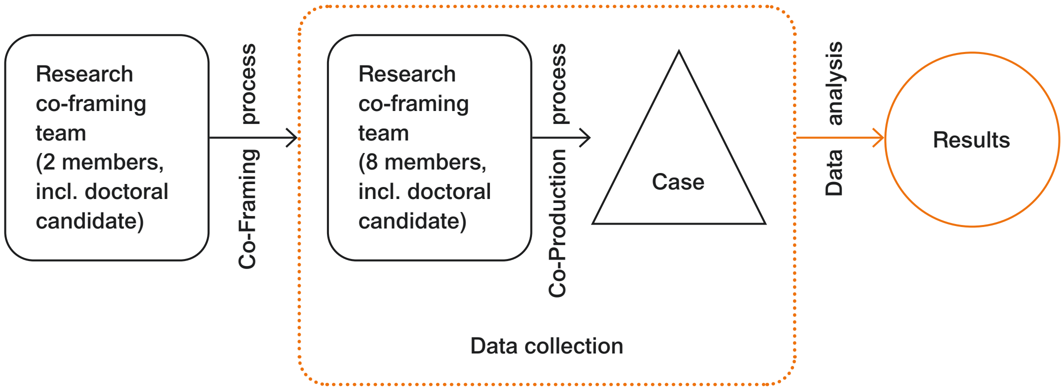

Fig. 13 Data collection process of Paper 3. The case was a new type of GI element, the Vauhtitie wetland. Data were collected through interviews of members of the private–public team that led or participated in the design process of the element.

The researchers conducted seven interviews with the wetland project team, resulting in a dataset of 7.5 hours of recorded discussions. The researchers conducted thematic analysis on the data, coding the data, creating themes based on coding and re-reading, and drawing a thematic map.

3.7 Case 4: Designing Multifunctional Sustainable Urban Drainage Systems

In Paper 4, ‘Can We Really Have It All? ——Designing Multifunctionality with Sustainable Urban Drainage System Elements’, the focus was on the challenges of measuring multifunctionality as a design outcome of a GI element. The delivery of multiple benefits is an essential part of both the GI-based and water-sensitive approaches (Fletcher et al., 2015; Hansen and Pauleit, 2014; Hansen et al., 2015). However, how the benefits relate to each other is vaguely defined, thus highlighting a lack of knowledge on how they could be promoted in the actual design process. Difficulties in measuring success arose in Paper 3 as well. In Paper 4, multifunctionality was studied with the help of a case study and related sustainable drainage system scenarios. The specific research question of Paper 4 is ‘How can the level of multifunctionality of GI be estimated during the design process?’

The co-framing and co-production process was implemented by a group of three researchers (the doctoral candidate with another doctoral candidate, Ambika Khadka, and Senior University Lecturer Teemu Kokkonen from Aalto University’s Laboratory of Water Resources). The researchers collected data to answer the research question regarding the three co-produced scenarios, displaying alternative solutions for SUDS in the case site, which was the Kirstinpuisto residential area in Turku, Finland.

As displayed in Fig. 14, the scenario co-production was supported by a workshop held with local civil servants to discern the local ES demand and set targets for the development of the case-study area. The doctoral candidate participated in this workshop as a facilitator, providing the civil servants with scientific knowledge related to ES. The workshop also provided insight into the co-production process used to generate appropriate scenarios and understand local targets.

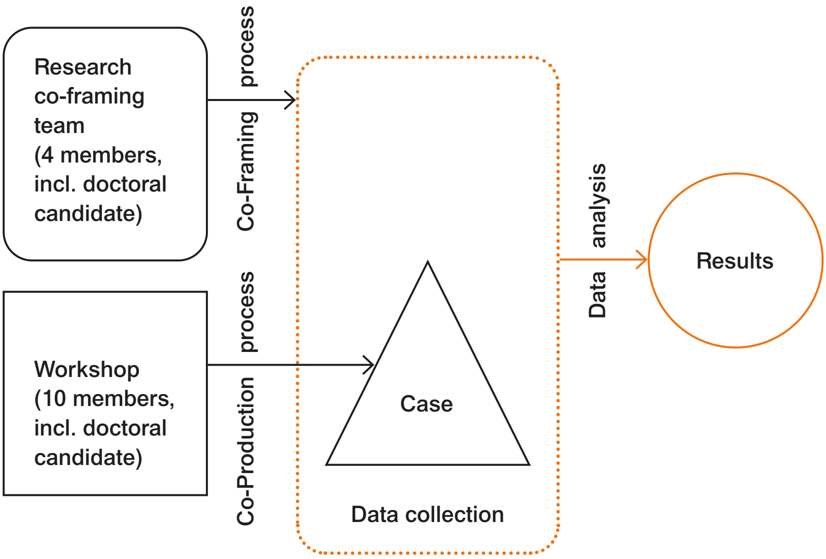

Fig. 14 Data collection process of Paper 4. Data were collected by quantitatively analysing three alternative scenarios co-produced for the case site. Co-production was informed by a target set workshop.

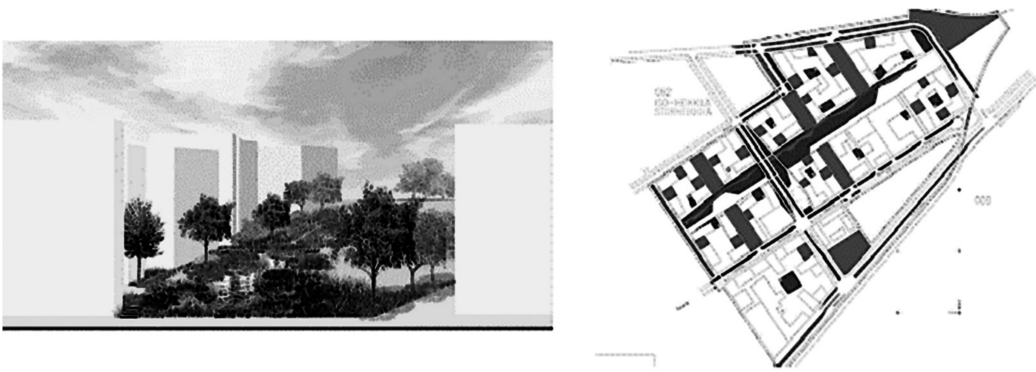

Fig. 15 Depiction of one of the scenarios (NORM) co-produced in Paper 4.

Three co-produced scenarios (RUN, NORM, and MAX) formed the dataset of the research. Each scenario had a different set of SUDS. In RUN, the existing pipe network was supplemented with open swales. In NORM, water detention SUDS were added in residential yards (Fig. 15), and MAX comprehensively maximised the number of SUDS elements. In each scenario, the analysis addressed the four criteria of multifunctionality, which were set by water management guidelines (C753 SUDS Manual): water quantity, water quality, amenity value, and biodiversity value.

Analysis methods included hydrological modelling for water quantity and quality management. Both amenity and biodiversity values were analysed using quantitative measuring in two phases. The amenity values were assessed based on their links to the mental health benefits provided by urban green and blue structures. The first parameter involved measuring the total area of SUDS elements with vegetation that is easily visible from residential windows or yards, streets, or other public spaces. The second parameter involved measuring the total area of surfaces in which people can perform activities or interact close to SUDS elements with vegetation.

As with amenity value, two parameters were used to assess the biodiversity value of SUDS scenarios. The first parameter used the structural heterogeneity index score developed by Monberg et al. (2018). The second parameter was derived from connectivity and the edge effect, because these factors also enhance biodiversity. In addition to the analyses, the mutual interconnections delivered by multifunctional benefits were discussed in the paper.

4 MAJOR FINDINGS

This chapter presents and reframes the main findings of the published papers by grouping the results of the papers under four themes: *growing capacities, critical barriers, multifunctionality,* and a *systemic approach* (Fig. 16). These themes are further elaborated on as they relate to the planning and design level according to the case studies. The themes contribute to the dissertation aim of understanding how to co-create GI and what kind of further implementation is needed to make GI's contribution more effective in sustainable and resilient landscapes and in urban planning and design. A discussion of these findings is presented in Chapter 5.

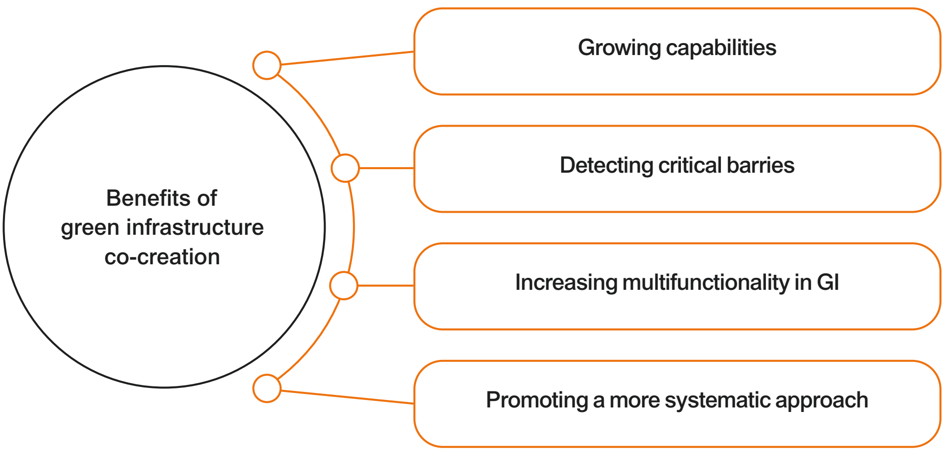

Fig. 16 The four themes under which the main findings of the papers are categorised.

4.1 Growing Capacities

The findings from the papers confirm that co-creation processes can positively affect the implementation of the GI-based approach and increase participants' capacities to apply scientific knowledge and combine science with existing practices. Most explicitly, the results of Paper 1 illustrate that co-creation facilitates developing and integrating scientific knowledge into planning, as an understanding of GI gradually evolved among participants (Fig. 17).

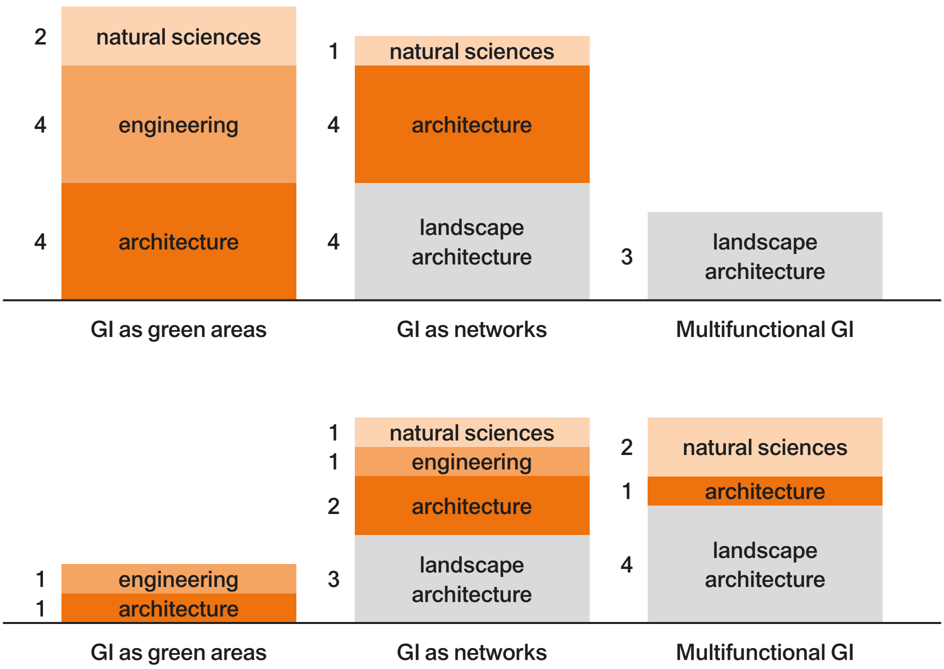

Fig. 17 Evolution in the understanding of the GI concept during a co-creation process organised around the multidisciplinary collaboration and understanding of green infrastructure in the cities of Tampere, Vantaa, and Jyväskylä (Finland). Top: before the co-creation process, bottom: after the co-creation process. (Paper 1)

For instance, as presented in Paper 1, at the beginning of the case-site co-production in the cities of Tampere, Vantaa, and Jyväskylä, the thinking of some practitioners was influenced by the traditional spatial and functional classification of single green spaces, which are still used in conventional planning practices. Afterwards, practitioners could recognise the importance of enhancing mutual social and ecological interactions and the benefits that people and local communities can obtain from GI. Moreover, the understanding of GI as a systemic entity that can be integrated within the built environment increased significantly, as displayed in Fig. 17 and as indicated in the following quote.

> *GI is an entity formed by green and blue elements that are part of the urban structure. GI includes processes and services that nature provides for humans. (Written definition of GI in a questionnaire after co-production workshops, Paper 1)*

Furthermore, the overall co-creation process resulted in some changes to the policy approaches and land-use practices that were being applied in the case-study sites. A common understanding was generated among the participants about the need to incorporate GI development within public buildings and spaces. Additionally, the participants recognised the importance of involving constructors and considered new types of GI elements, such as green facades and green roofs.

In addition, GI co-creation facilitates understanding of the baseline situation and increases the comprehension of new concepts and approaches, as in the case of the cities of Tampere, Vantaa, and Jyväskylä (Paper 1) and the Helsinki stormwater programme development (Paper 2). In these cases, those involved identified possible improvements, such as the need for an easily accessible database with technical information.

Additionally, the results from Paper 3 revealed that the novel character of the GI made progress and decision-making particularly challenging in the Vauhtitie wetland design project. The co-production phase of the design, the incorporation of scientific knowledge about ESs, and the development of open discussions concerning GI benefits led to a mutual understanding of GI multifunctionality and crystallised in a successful project outcome. Furthermore, several organisational or individual abilities that foster co-creation were identified, such as the role of change agents and project management and the increased capacity to see the big picture or to step out of one's domain of expertise, as demonstrated by the following citation:

> *...all came a bit closer to each other, which was really good. What it comes to a good project, it is that all are inspired at least a little and try with a solution-oriented approach to create possibilities together and let us proceed. So, these people did not hold on to their own opinions too tight in the end. (Expert interview, Paper 3)*

4.2 Critical Barriers

Through analysis of the co-creation processes, the papers also captured some of the critical factors and barriers affecting the effective usage of the GI approach in landscape and urban planning and design. Generally, as GI and SUDS are emerging concepts, knowledge-related barriers were detected on both the planning and design levels. In the workshop discussions analysed in Paper 2, it became evident that not all stakeholders shared the same skills and understanding. As a result, knowledge-sharing and management problems were identified, such as clinging to existing routines. These issues generate a path dependency, which is a situation in which socio-institutional routines of past practices prevent the adoption of better alternatives even when they are available.

In addition, the terminology of different types of SUDS elements is only vaguely known, and the details of practical management and the functionality of different SUDS components were not well understood. For example, as methods to decrease urban runoff, stormwater infiltration and permeable surfaces were mentioned much more often than detention structures.

Lack of knowledge was discussed in Paper 3 too. Despite the increased awareness of sustainability issues, interviewees expressed frustration about the lack of clarity of concepts related to sustainability, GI, and ESs. The interviewees asserted that neither general acceptance nor understanding of these concepts exists yet among stakeholders. Additionally, although sustainable development could be considered a guiding principle within the project, it was not used as a reference point by the participants. Furthermore, a general lack of roles and responsibilities was identified in both cases studied in Papers 2 and 3, which is an issue when questions of investment are discussed, as indicated in the following citation:

> *...Who is responsible and who pays? If we proceed, one is responsible to a certain point and another after that. How does this affect cost-sharing? So, who has the responsibility and for what? (Expert interview, Paper 3)*

4.3 Multifunctional Green Infrastructure

As revealed through the co-creation processes developed in different case studies, among the barriers that hinder the implementation of the GI-based approach, one theme rises above the others: multifunctionality. Even though multifunctionality is regarded as one of the cornerstones of the GI-based approach and co-creation can help to manage it, as presented in Papers 1, 3, and 4, it is still constrained by various challenges. First, when the understanding of multifunctionality is limited, not all related benefits are considered, and not all potential stakeholders are recognized. The results of Paper 2 show that recreational possibilities and environmental benefits, such as the biodiversity provided by SUDS, were highlighted in several workshop discussions. However, additional ESs, such as air quality improvement, mitigation of and adaptation to climate change, energy savings through shading and insulation, and the reduction of the formation of urban heat islands, were not discussed in the same manner.

Because of the narrow understanding of multifunctionality, the full set of potential stakeholders is not recognized. It was commonly accepted among participants that the value of the benefits delivered by SUDS accrues only to direct stakeholders, such as those affected on the maintenance side. The monetary value of the potential ESs (such as health benefits) was not mentioned in the discussions. This impedes adoption of the GI-based approach. When the value of SUDS-related benefits is not completely understood, it is difficult to justify the SUDS-related investments, which are typically higher than those needed for traditional drainage systems given the novelty of the structures.

> *When thinking about investing costs and maintenance costs [of SUDS elements] how are they related? I'm not familiar with this at all.*
>
> *It is a bit tricky because a constructor is not normally responsible for maintenance. It doesn't matter to them if the solution is better or cheaper in the long run. They only go for something new if they are forced to do so.*
>
> *That is the reason why we should emphasise piloting when we are developing public open spaces. In the maintenance phase, the saving could be the possibility of utilising water in irrigation.*
>
> *Yes. Should you add the irrigation in the potential benefits here? (Workshop discussion, 26 April 2017, Paper 2)*

Second, co-production of case sites revealed that multifunctionality makes the measurement of the result ambiguous. The workshop discussions recognised the lack of indicators and methods to monitor the implementation of the GI-based approach (Paper 2). Similarly, the results in Paper 3 showed that, because of the lack general acceptance or understanding of GI-related concepts or preferred outcomes, the success of the project remains unclear. Valuable trees, biodiversity, recreational services, health effects, and climate change adaptation were all discussed during the co-production process along with water quality and quantity and investment costs, but the comparison of benefits was challenging.

Whereas the effects of a purely technical solution are easy to measure, ecological systems create several uncertainties and difficulties in measurement. Correspondingly, interviewees contended that it is difficult to discuss something that is challenging to identify and measure (Paper 3). Therefore, the outcomes of a GI solution are perceived to be ambiguous and difficult to predict and quantify and to lack cause-and-effect relationships.

> *Related to those non-material benefits, a system needs to be developed for them, how they are calculated, too.… Health effects, recreational effects, and landscape impacts and things, which do not have a price tag really. (Expert interview, Paper 3)*

Third, providing multifunctionality to match the local needs is challenging. In Paper 2, the workshop attendees shared the common understanding that stormwater runoff should be managed to achieve maximum benefits in the urban environment. However, the attendees lacked knowledge of how to achieve this, as illustrated in the following discussion:

> *I have listed some very general and nonspecific principles here. In general, we should use more intensively green structures and infiltration and question the use of pipe drainage. Especially in the upper parts of the watershed, like, do we need to put water in the pipes every time? These measures are related to the implementation of the priority order. However, I haven't added who does it, or how it is done, or what is the practical action.*
>
> *Yes, these are very important issues. And it is very difficult to take it a step further. Like what would be the elaborated solution.*
>
> *Yes, [it is difficult] to name who does what. (Workshop discussion, 26 April 2017, Paper 2)*

The results of Papers 2 and 4 revealed that the stakeholders were not fully aware of the differences in SUDS solutions in terms of biodiversity. Co-production in Paper 4 showed that, in principle, SUDS that sustain the function of natural processes uphold biodiversity (Paper 4). For the needs of biodiversity, it is essential to design volumes, routes, and surfaces that enhance the water cycle and sustain biophysical structures, processes, and functions. The amenity and biodiversity values delivered by a scenario were highly dependent on the presence of SUDS elements.

The ability of SUDS to store and ensure the availability of water for vegetation enhances biodiversity through ecological processes. If the delivery of multifunctional benefits is not considered during the design process, it is quite unlikely any goals related to multifunctionality will be achieved. The SUDS elements potentially have a special role to synergistically provide for local hydrology, biodiversity, and amenity values if conditions for those parameters are understood and created during the design process. Moreover, co-creation should facilitate the integration of different types of knowledge, interests, concerns, needs, and expectations.

4.4 Systemic Approach

The demands for increased understanding of multifunctionality are paving the way to the recognition of a more systemic approach to facilitate the implementation of GI. As the GI-based approach is inherently complex, consisting of links and feedback within and between people and nature, the implementation of GI elements requires new types of decision-making and target-setting processes. However, as detected in the co-creation processes developed in all the case studies, challenges embedded in current planning and design practices prevent the use of a more systemic approach to promoting positive interactions between people and nature in the urban SES.

The findings in Paper 1 reveal that new issues such as stormwater management and the urban micro-climate need to be addressed more comprehensively in urban planning. However, rigid planning practices pose serious obstacles. The workshop attendees stated that the GI-based approach should optimally be incorporated at the intermediate stage of the planning process, between the well-established phases of master and detailed planning.

Architect 1: *'We actually need an "area development planning", in order to get a comprehensive picture of GI within and outside the selected site'.*

Engineer: *'Maybe we could outline the green and blue networks at the upper level which would guide a detailed planning'.*

Natural scientist: 'Yes, that would be essential. Although our lead has stated that the GI should be embedded in the master plan. However, the current master plan does not provide a wider and more concrete picture for the development of GI'.
Architect 2: 'At the moment, Finnish cities have a strategic master plan'.
Natural scientist: 'Yes, we would need an area development planning phase in between the strategic master plan and detailed plan'. (Round table, 1 December 2015, Paper 1)

This view is supported by the results in Paper 2. According to the workshop discussions, a holistic watershed-scale approach was lacking in urban planning, and stormwater management was only considered at the start of the detail-planning phase. In addition, as the details of practical management and the functionality of different SUDS elements were not well understood, they were considered more alternatives than complementary to each other. This hinders the integration of stormwater management into urban planning. Accordingly, in Paper 3, the interviewees criticised the dispersed nature of city planning and decision-making and called for the management of larger entities and the engagement of different actors.

The results of Paper 4 demonstrate that the co-produced NORM and MAX scenarios that combine several SUDS elements reduce both the peak flow and the total flow volume of stormwater by detention, evaporation, and infiltration (Table 1; see the explanation of the scenarios in Section 3.7). Furthermore, these scenarios provide better results than the RUN scenario in all measured qualities (Tables 2 to 4), indicating that the amount of managed water helps SUDS to perform better by other indicators as well.

However, if the amount of water is not in line with society's needs, flooding or drought can occur. Therefore, designing SUDS to create high amenity and ecological values in urban greenspaces without generating societal, environmental, or safety problems requires a thorough understanding of the hydrological process. This principle can evolve into a systemic approach in which the functionality of SUDS is enhanced by locating them not as individual elements or part of a strictly water-related treatment train but as part of the larger ecological or green network.

Events	Scenarios	Peakflow Rate with SUDS [l/s]	Current State Peak Flow (l/s)	Decrease in Peak Flow (%)	Reduction in Total Volume (%	Reduction in Flooding Volume (%)
E1	RUN	1493	1876	20.5	2.0	66.0
	NORM	989	1876	47.3	39.9	81.1
	MAX	458	1876	75.6	81.0	98.7
E2	RUN	1493	1834	18.6	1.4	65.0
	NORM	957	1834	47.8	25.6	81.8
	MAX	442	1834	75.9	67.8	98.9
E3	RUN	360	474	24.2	-8.8	91.1
	NORM	249	474	47.6	33.8	98.5
	MAX	94	474	80.3	82.0	100.0

Table 1 Water quantity: Changes in the peak flow, total runoff, and flood volume for SUDS scenarios compared to the current state. Rainfall data cover seven months (E1) consisting of an extreme event during summer (E2) and an intense event after summer (E3) (Paper 4).

	Unit	RUN	NORM	MAX
Turbidity	NTU	−1.6%	11.6%	46.5%
Total suspended solids (TSS)	mg/l	−0.4%	3.0%	12.2%
Chromium (Cr)	µg/l	−2.6%	18.3%	73.5%
Copper (Cu)	µg/l	−0.2%	1.7%	6.8%

Table 2 Reduction in mean turbidity and concentrations of chromium, copper, and total suspended solids for SUDS scenarios compared to the current state, reflecting the capacity for quality management.

	Elements	RUN	NORM	MAX
Visible SUDS elements	Swales	0.6	0.6	0.6
	Rain gardens	0.6	0.9	1.8
	Bioretention cell		0.1	
	Visible green roofs		0.4	0.4
		1.2	2	2.8
Active Spaces Close SUDS elements	Lawns	1.7	0.7	
	Urban Square	0.3	0.3	0.1
	Yards		1.9	1.8
		2	2.9	1.9
Total Score	(ha)	3.2	4.9	4.7

Table 3 Amenity values: Total scores of the analysed amenity values of SUDS scenarios (Paper 4).

Elements	RUN	NORM	MAX	Elements	RUN	NORM	MAX
Swales	11	11	11	Between two SUDS el.		940	875
Rain gardens	6	9	18	Between SUDS el. and lawn	875	410	
Bioretention cell		2		Total score	875	1355	875
Total Score	1.2	2	2.8				

Table 4 Biodiversity: Total scores of structural heterogeneity (left) and edge line (right) of SUDS scenarios reflecting biodiversity (Paper 4).

The research results from all papers indicate a need for continuous knowledge exchange and development work to set new administrative norms and practices that enable the valuation and integration of GI elements as a part of existing technical systems. The results from Paper 1 highlight that more concrete actions involving different types of stakeholders could increase learning about GI and the approval of GI strategies and actions. According to the results of Paper 2, a successful transition to the GI-based approach requires new formal and informal agents and networks that strengthen linkages across systems and enable knowledge exchange. Co-creation can encourage such an integrated approach.

Moreover, the results of Paper 3 suggest that in the design process of the Vauhtitie wetland, because the movement of water does not recognise administrative boundaries, the co-production involving different organisations was required for a successful result. Careful design and promotion of the ES approach were required to integrate new social, technical, and ecological functions in a culturally significant urban area. The design process express the ongoing systemic change, which invited co-creating stakeholders to deal with various uncertainties and accept the process of constant learning.

Likewise, Paper 4 demonstrates that optimising multifunctionality leads to a systemic approach. The NORM and MAX scenarios that combine several SUDS with different features provide better quantity and quality management in conjunction with higher biodiversity and amenity values. The results facilitate the understanding of the ways in which different variables and assessment criteria are interrelated (Fig. 18). The ability of SUDS to store and ensure the availability of water for vegetation enhances biodiversity through ecological processes. In turn, biodiversity and the amount of vegetation in SUDS enhance evaporation and infiltration, subsequently affecting water quality. Additionally, increased biodiversity positively affects the perceived amenity value, but an increased amount of water in urban greenspaces simultaneously requires higher design skills to provide amenity value.

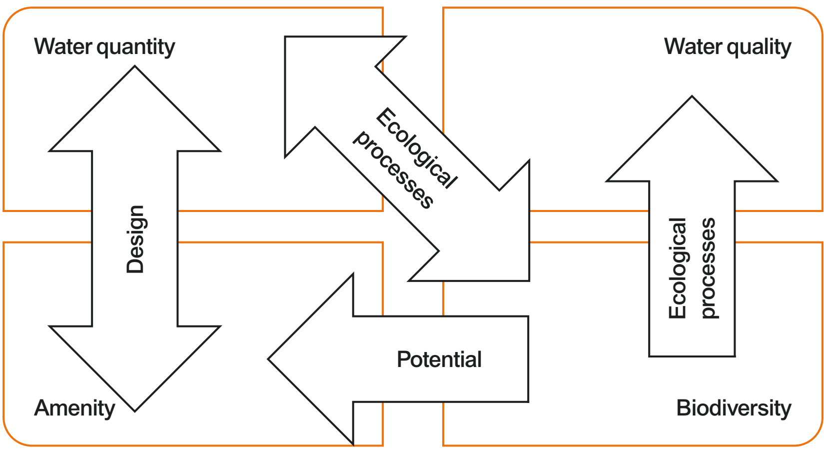

Fig. 18 The interrelations among multifunctionality criteria according to Paper 4.

A temporal dimension also exists in the provision of multifunctional benefits. Some of the expected outcomes can be precisely measured during the design phase (such as water quantity management) or later, after its realisation (such as the richness of plant species). However, some of the outcomes emerge through the dynamic interactions among new residents or users, new hydrological or soil conditions, maintenance procedures, and a changing climate. Moreover, these interactions reveal the processes affecting complex systems and the need to shift from linear certainties to adaptive and responsive systems. Strengthening the multifunctional benefits requires an understanding of the ecological processes and system dynamics in urban greenspaces. However, these concepts are still not familiar to all stakeholders, as revealed by the following citation:

Architect: 'There is a challenge when we want to achieve biodiversity conservation on the site and all around, but at the same time, we have huge ambitions for new buildings. What happens to the biodiversity then … in that conflicting game?'
Engineer: 'Well, green roofs … when we build high buildings, there will be unused land and space on the roofs'.
Architect: 'Yes, but is it then fully available to residents if nature is on the roof?'
Moderator: 'It could be, but how will all cyclic processes function when nature is all limited to the roofs?'
Engineer: 'Cyclic processes? What are those?'
Moderator: 'Like nutrient and water cycle'.
(Workshop in Tampere, 15 September 2015)

5 DISCUSSION

5.1 Theoretical Implications

The GI-based approach has been identified as a promising framework to integrate natural processes within spatial urban development policies, and this approach could be enhanced by co-creation. This thesis helps us to understand how to co-create GI within landscape and urban planning and design in Finland and to determine what kind of further implementation is needed to make the contribution of GI more effective. In the appended research papers, the incorporation and implementation of the GI-based approach have been investigated through case studies at different levels ranging from strategic urban planning to the design of urban green areas.

The results of the research papers confirm the earlier understanding from the literature (Lennon et al., 2016; Faehnle et al., 2014; Ahern et al., 2014; Kopperoinen et al., 2014; Lafortezza et al., 2013; Mell, 2010; O'Donnell et al., 2017) that interdisciplinary co-creation with stakeholders potentially facilitates the generation of multiple benefits and further enables different stakeholders to reframe how they develop and manage the landscape. In addition, co-creation promotes the use of scientific knowledge as part of the planning and design processes and enables the evolution of a deeper comprehension of GI for all stakeholders (Pauleit, 2019; Haase, 2017).

Furthermore, the results indicate that co-creation facilitates understanding of the current barriers that hinder the implementation of the GI-based approach, and they offer a more precise scope as to where GI-related co-creation could be integrated into landscape and urban planning and design. The case study projects and related cities seeking to enhance the GI-based approach or concrete GI solutions face various challenges and should work on several areas simultaneously.

These results build on the evidence provided by Brown et al. (2013), showing that the implementation of the GI-based approach has been difficult because of existing routines, infrastructure, and institutions, which are persistent and highly interwoven. Co-creation brings together different skills and agendas, allowing the development of new approaches and solutions. Moreover, it enables the development of joint acceptance, as new GI practices benefit from the approval of a wide range of stakeholders, including some stakeholders who have not traditionally been interested in green areas or stormwater management, such as the health and education authorities (Ashley et al., 2015).

In addition to investigating how to co-create GI, this thesis has had two additional aims: to determine how co-creation can promote the development of more multifunctional GI in planning processes and to explore how co-creation can inform and support the design processes of multifunctional GI. Despite multifunctionality being acknowledged as the cornerstone of the GI-based approach (Hansen and Pauleit, 2014; Hansen et al., 2015), challenging definition of multifunctionality of GI elements was identified in this study as one of the key barriers to the approach's effective use and implementation. This is one specific outcome of this thesis.

The results show that the understanding of multifunctionality is still limited. Not all related benefits and their mutual interconnections are fully understood, and the recognition of possible stakeholders is still restricted. Furthermore, multifunctionality makes the measurement of the results of planning or design processes ambiguous, and challenges exist in providing multifunctionality to match local needs. These findings agree with the argument by Meerow and Newell (2017) that most GI-related research and planning has focused only on a handful of benefits. Likewise, Hansen et al. (2019) stated that the operationalisation of multifunctionality in planning and practical examples is still lacking.

According to the results, the difficulty in measuring the multifunctional effects of GI hinders the transition from the more traditional planning approaches to more systemic approaches in which technical systems are integrated with ecological systems. This confirms that we need a better understanding of the implicit characteristics of the desired multifunctionality and how it can be achieved (Wang and Banzhaf, 2018).

For example, when SUDS are used as a retrofit solution or as part of a new greenspace with the expectation that they will provide multiple benefits, a knowledge gap exists concerning the contribution of SUDS to the local biodiversity, such as knowing which elements support which species and habitats. This insufficient understanding of the multifunctional potential of GI elements (i.e. different types of SUDS) reveals that green structures and stormwater management are still perceived as separate issues instead of key components of complete SESs.

In addition, results confirm that the GI-based approach offers a new lens that can connect previously separate functions, such as recreation, drainage, and conservation, into a more complex SES combining not only urban hydrology but also potential ecological and sociological benefits through multifunctionality (Flynn and Davidson, 2016; Winz et al., 2011). Moreover, new functions, such as carbon sequestration and climate adaptation, have drawn increasing attention and thus bring new demands for multifunctionality.

As the comprehension of multifunctionality inevitably leads to a systems approach, co-creation of GI in the context of landscape and urban planning and design can accelerate the adoption of the GI-based approach by defining *an accelerating model* (Fig. 19) towards SESs. As stakeholders develop new capacities, they increase their ability to recognise additional critical barriers hindering the implementation of the GI-based approach. Many of these barriers are related to multifunctionality, which calls for a systems approach to successfully meet the need for SES thinking (Folke, 2016). A systemic approach implies that communication between stakeholders with differing backgrounds and interests must be strengthened to create new understanding and new relationships. Consequently, the promotion of a systems approach requires co-creation, which, if done successfully, leads to capacity building and the identification of further barriers, thus allowing adaptive governance (Assche et al., 2019).

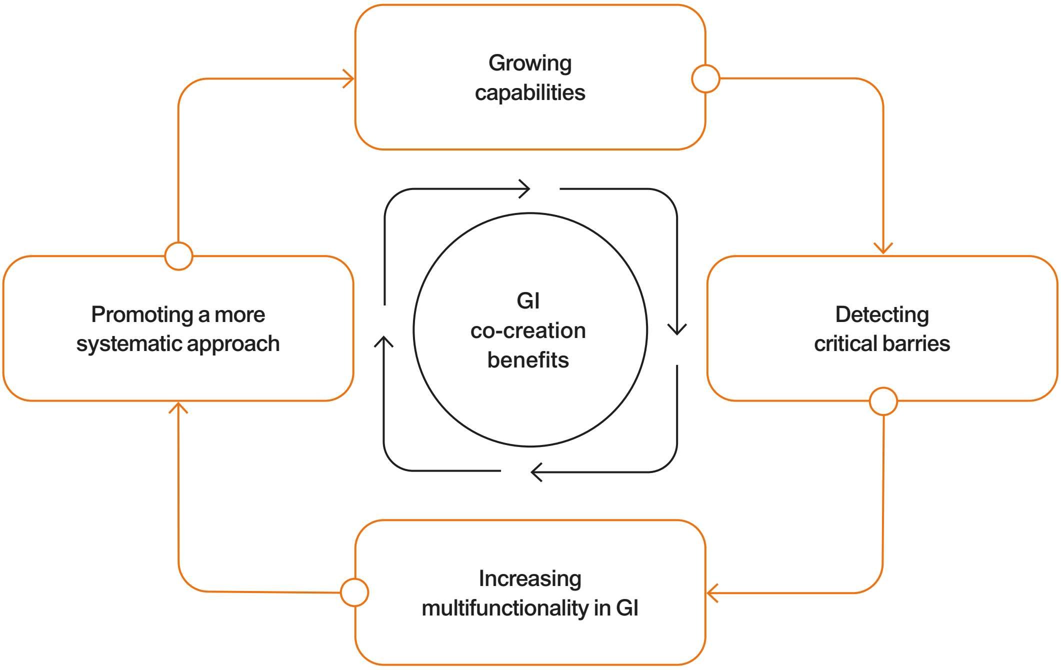

Fig. 19 The accelerating trajectory towards more performative and multifunctional GI enabled by co-creation. Co-creation enables increased capacity to detect critical barriers, which increases the understanding of multifunctionality, leading to a more systemic approach, further capacity building, and increased SES thinking.

5.2 Green Infrastructure and Adaptive Governance

It is interesting to examine the types of capacities generated through the accelerating model. The results show that planning and design processes that lead to the production of a multifunctional GI require a deep and interconnected understanding of various matters: local hydrology and water dynamics, ecological processes essential to biotic growth, and the ES demands of the local community. Furthermore, the mutual interactions of these matters must be properly addressed, confirming the notion by Fletcher et al. (2013) that the interactions between the components of the urban water cycle are as important as the individual components.

This implies the need for a deep comprehension and application of the ES cascade model (Potschin and Haines-Young, 2011), including the provision of ESs by biophysical structures, processes, and functions and the related benefits and value to society (Fig. 20). More critically, various effects of planning, design, construction, and maintenance of urban biological structures and processes on the provision of ESs are also clarified by co-creation.

The results of this study indicate that successful adoption of a GI-based approach requires a thorough comprehension and application of the ES cascade model, which applies not only to the small-scale design level and stakeholders involved directly in the local circumstances but also to the planning level and associated stakeholders. Co-creation expands the set of stakeholders to a larger group of experts, including experts who are not traditionally familiar with or who do not work with ecological processes, such as architects and traffic and civil engineers, as shown in Papers 1 and 3.

Through co-creation of GI, natural systems and the effects of human actions on them are introduced and explained to these new stakeholders, enabling the enlargement of their core competencies.

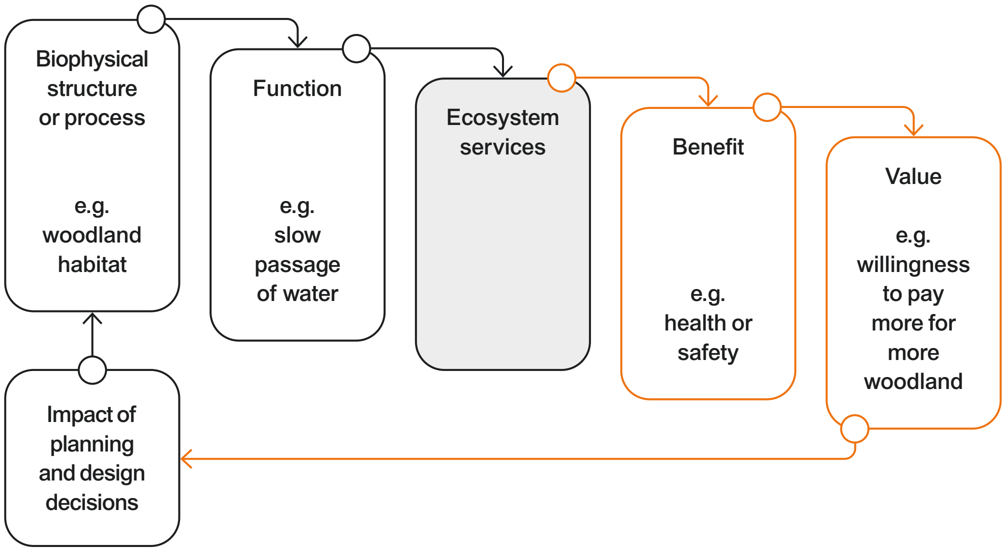

Fig. 20 Through co-creation of GI, natural systems and the effects of human actions on them are introduced to stakeholders, enabling the enlargement of existing competencies: the cascade model of ecosystem services helps us to understand that wellbeing of the nature is in line with human wellbeing and decisions in planning and design processes should be made accordingly (the cascade model adapted from Potschin and Haines-Young, 2011).

This approach challenges conventional urban planning practices in which social and ecological processes are often considered to be conflicting rather than synergistic forces (Kabisch, 2015); therefore, co-creation of GI can be considered a key and strategic game-changer, promoting systems thinking and leading urban development towards constant learning and other adaptive governance practices (Assche et al., 2019) and, therefore, towards more sustainable urban SES.

5.3 Practical Implementation

With the recognition of the accelerating model as a potential roadmap to transitioning the urban SES to sustainability and adaptive governance, new ways to enable co-creation of the GI-based approach should be sought. Both research results and the literature (Kambites and Owen, 2006; Wong and Brown, 2009; Lennon et al., 2016) offer advice for practical requirements that enhance the implementation of the GI-based approach through co-creation.

Earlier studies have shown that, at the beginning of any social transition, the work of a small group of frontrunners can be remarkable in introducing the basic skills, knowledge, influence, and resources required to navigate the transitional pathway (Dunn et al., 2017). Nevertheless, in the acceleration phase of transition, institutional work is essential. New approaches cannot be developed in isolation but must be socially embedded in the existing institutional context.

The existing context includes increasing institutional connectivity and governance across institutions at multiple levels, improving the operational connections and partnerships between different administrations, and improving the ability to experiment with scaling up innovations (Dunn et al., 2017). Most critically, it is essential to challenge the traditional planning and design practices that direct their attention to the provision of single functions. Instead, the enhancement of ecological processes and functions should structure urban planning to secure ES provision and related multifunctional benefits and to increase the functioning of the city as a deep SES.

In this thesis, the co-creation of the GI-based approach has been tested, especially at the intersection of the urban landscape planning and water management sectors (Papers 2, 3, and 4). This has proved to be productive because water management is an issue that must always be solved within urban development projects. There the accelerating model created by co-creation has the potential to give a more forceful push towards a regime shift. In addition, climate change adds pressure to find new methods and solutions for urban water management and urban environmental planning, so it is highly recommended to use the co-creation of the GI-based approach as a working method to find and test multifunctional solutions to urban water and urban nature issues on different scales.

Furthermore, the results also enable us to reflect on the use of co-creation processes as an action research method – that is, when and in what contexts this approach is appropriate and effective. Results give evidence that co-creation increased participants' capacities to apply scientific knowledge and combine science with existing practices. In addition, the results imply that the local orientation of collaborative processes, for which the approach has been criticised (Sutherland et al., 2017), has become a strength when dealing with GI and urban sustainability. The process of designing a successful multifunctional GI always requires local-scale exploration and, as stated in the previous section, provides new insights into dynamic relationships between people and ecological systems. Understanding of this interaction on a local scale enables enlargement of that understanding to the planetary scale and could further empower the systems-level transformation. And in the end, cities are physical structures, where concrete sustainable solutions need to be designed and built from the roots level upward.

5.4 Limitations and Proposed Further Research

The research was based on a close collaboration with four cities in Finland where the local authorities were interested in exploring the potential that GI could have in urban development. Therefore, the results and limitations of this research should be understood within that scope. Cases studies represent typical and actual urban planning situations, which increases their utility. National planning policies that guide practical planning actions guarantee that findings can be adapted to other Finnish cities. However, the results were derived from Finnish case studies, which restricts the application of the results to local planning and design processes. Still, the main findings concerning the challenges related to the multifunctionality benefits provided by co-creation and the associated concept of the accelerating model are supported by the existing research and can be applied to a wider context.

The chosen research methodology, the action research case-study strategy, implied a deep involvement of the author, collaborators, and stakeholders in most of the activities, with subsequent effect on the replicability of the experiments. Action research is concerned with action and learning, and this was purposefully chosen as the overarching research method to gain in-depth knowledge about the implementation of the GI-based approach to transfer GI-related knowledge from research to planning and design practice and to advance the related regime shift.

However, there are some disadvantages to action research. First, there can be difficulties in distinguishing between action and research and ensuring the application of both, and second, it has been regarded as a highly resource-intensive method (Mackenzie et al., 2012). The researcher has a bigger role in providing information, facilitating the process, and agreeing on objectives and process transparency than would be demanded in more traditional research approaches. These issues were seen during this research. In particular, the workshop series organised for Paper 1 required time resources and substantial collaboration. Then again, if 'science needs to be positioned differently in the world, through integrating new ways of knowing into new ways of making decisions and acting across all spheres of social, economic, and political life' (Wyborn et al., 2019, p. 320), it self-evidently requires involvement and resources, distinct from more traditional research approaches.

Furthermore, lack of repeatability can be seen as one of the challenges with action research and the case-study approach (Mackenzie et al., 2012; Yin, 2014). Involving 60 people across five organisations and involving eight research colleagues from different disciplines (landscape architecture, urban planning, environmental sciences, administration, and water management) provides advanced interdisciplinarity and rigour in the study. The selection of specific research methods from content analysis to quantitative measurement with the elaboration of the co-creation model provides new possibilities for landscape architectural research to have an impact on the actual environmental and societal challenges. Moreover, the research confirmed the frequent need to combine different methods of inquiry and research in this discipline (Deming and Swaffield, 2011; Van den Brink et al., 2016).

The results of this thesis provide new possibilities for future research. First, it would be beneficial to gather further feedback from the research case studies, their future development, and involved stakeholders to analyse the long-term impact of the co-creation process. Moreover, as the multifunctionality of GI elements proves to be challenging, it is important to further study the ways different factors in multifunctionality interact with each other and how they can be assessed holistically. Understanding these factors and their relations facilitates designing and implementing GI and GI elements that contribute most to SESs.

In addition, further research is needed to determine the relevance and value of GI, ESs, and related networks, structures, and functions more objectively. The sustainability advantages provided by short distances in the ideal compact city should be evaluated against the space requirements of ecological processes and hydrology. The thesis includes co-creation processes involving civil servants, researchers, and professionals in landscape and urban planning and design. In future research, it would be advisable to enlarge the stakeholder groups to include other professionals and inhabitants as the direct beneficiaries of the GI-based approach and to test the relevance of co-creation and the associated accelerating model with them.

The enlargement of the stakeholder groups would further increase the multidisciplinarity of the research and tackle the criticism that has been levelled against co-creation processes as reinforcing the power of policy elites or those who have capacity to engage and thereby marginalizing those with alternative perspectives (Lövbrand, 2011; Turnhout et al., 2020). Designing future research projects in an appropriately inclusive fashion links to the concepts of environmental justice and capabilities, both related to ESs. Environmental justice will be achieved when 'everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work' (USEPA, 2017). In line with this, the capability approach sees that ESs comprise resources that are available according people's capability (Polishchuk and Rauschmayer, 2012) that can differ among socio-economic groups. Therefore, the development of the city as a functional, deep SES requires an equitable, people-centred approach.

5.5 Final Conclusions

This doctoral dissertation examined how co-creation can support the definition of more multifunctional and systemic GI and what kind of further implementation is needed to make the contribution of GI more effective in sustainable and resilient urban transitions. According to the results and existing literature, the GI-based approach challenges planning traditions and the conventional methods through which we have envisioned and constructed our cities. Thus, through the provision of ESs, we can comprehend that natural systems in the urban environment can contribute so much more than just recreational possibilities or the conservation of habitats. The aim should be to steer urban development towards integrated land-use governance of the urban SES, where the potential for multifunctional ESs is realised by enhancing the positive synergies between abiotic, biotic, and social systems.

Recognition of urban SES can help align social and ecological systems so that they benefit from each other. However, both are complex systems that are difficult to understand and predict. Implementing the GI-based approach and supporting the planning and design of GI elements through co-creation helps to reorganise the effects of our actions and processes towards biophysical structures and natural processes in urban areas and to better provide the desired ESs. Thus, co-creation can support the use of the GI-based approach as a game-changer facilitating the ongoing regime shift to adaptive governance, enabling systemic change from technocratic and reductionist practices to a wider SES approach in both landscape and urban planning and design.

Bruno Latour (2017) stated that social and ecological systems are complex systems, marked by nonlinear responses to intervention, yet offering the possibility of new solutions and adaptations. Therefore, in the Anthropocene, it is important to recognise that co-creation has much to offer for new interdisciplinary knowledge creation, synergies, and innovations. Currently, the division between social and ecological is dissolving, and it is critical to comprehend that the GI concept can be an ideal ally to advance this progress.

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